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A REGIONAL GIS-BASED ANALYSIS OF ELK HABITAT SUITABILITY IN NORTHWESTERN NEBRASKA

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by

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The need to accurately assess the use and suitability of elk (*Cervus elaphus* spp.) habitat at regional scales will continue to increase as human development encroaches into what was once optimum elk habitat. The objectives of this research were to calculate the relative proportions of habitat use by elk in the Pine Ridge region of Northwestern Nebraska from a set of radio-collared elk locations and generate a habitat suitability model. Habitat variables (landcover type, aspect, slope, distance to a road, road density, and distance from the ponderosa pine edge) were measured for each elk location (n = 5,787 dating from April 1995 to August 1997) using a Geographic Information System (GIS). The habitat variables were also measured for a random point coverage (n = 5,787) to compare and contrast the differences, if any, between elk-use and non-use areas. A logistic regression model describing elk habitat selection for two discrete, non-migratory herds of elk was developed. Slope, distance to a road, road density, distance from the ponderosa pine edge, and several landcover types including ponderosa pine (>70% canopy coverage), ponderosa pine (40-70% canopy coverage), western mixedgrass prairie, and alfalfa were habitat variables found to be statistically significant ($p < 0.05$) in explaining areas used by elk. Habitat variables that were not statistically significant ($p > 0.05$) were aspect and the landcover types including small grains agriculture and fallow

agriculture. I used a GIS to apply the model to the entire Pine Ridge study area and create a map of potentially suitable elk habitat. The results of the logistic regression model suggest that the amount of suitable habitat in the study area ranges from low (34%), medium (38%), high (21%), and optimal (8%). I estimate that the Pine Ridge region provides 140,000 ha (540 mi^2) of high-to-optimal suitable elk habitat. This model may be used to direct management efforts to ensure that the number and distribution of elk in the Pine Ridge region is ecologically sound and socially acceptable.

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CHAPTER 1: INTRODUCTION

Introduction to Thesis

Survival of individual species or even entire populations will become more and more the responsibility of resource managers and comprehensive long-range management plans given the inevitable loss of habitat that will accompany the continuing growth of the human population. Wildlife managers face many dilemmas (habitat loss and fragmentation, reserve design, stochastic events, alternative habitat management scenarios) when evaluating the viability (probability of persistence into the future) of wildlife species. Habitat assessment and evaluation are often the first steps managers use in the process of creating management plans for a particular species or group of species.

The four basic components of habitat include: food, cover, water, and space (Skovlin, 1982). An organism's ability to survive, reproduce, and persist is a function of its ability to acquire and use each of these habitat components (Anderson and Gutzwiller, 1994). Organisms select certain habitats types more, or less, than would be expected if all habitat types were used randomly. Habitat selection can be measured, and habitat features can be evaluated to determine the suitability of habitat for a species. Habitat modeling is an effective way to summarize data collected about an organism and make predictions about potential habitat suitability.

The use of Geographic Information Systems (GIS) for assessing and modeling wildlife habitat is of growing interest to wildlife biologists, foresters, botanists, and environmental planners. A GIS is a tool that has the ability to store, analyze, modify, and retrieve spatial digital data to help resource managers make intelligent natural resource management decisions. By integrating spatial and tabular data into a GIS, individuals

Nebraska Elk Management Plan in January 1995. The plan recognized elk as a valuable component of Nebraska's native fauna. Under the management plan the NGPC would: 1) determine the population status of elk, maintain a minimum population of 100 elk with at least 6 mature (6-plus points) bulls, and obtain information on elk herds in parts of the state outside of the Pine Ridge, 2) respond to all elk depredation complaints, 3) conduct prescribed hunting seasons starting in 1995, 4) monitor the overall health of elk populations and prevent contamination of domestic livestock through removal or treatment of infected elk and, 5) provide informational and educational materials to the public, which recognizes free-ranging elk as a valuable component of native fauna (Nebraska Game and Parks Commission, 1995).

Elk Research in Nebraska

In recent years, a number of research studies have been conducted on the Pine Ridge elk herd. Specific objectives of these research projects were, but not limited to: estimate the size and sex/age structure of the elk herd; determine the relative spatial distribution of elk to timber harvest, agricultural crop production, livestock production, roads, and human dwellings; and estimate the distribution and habitat characteristics of elk calving areas (Stillings, 1999) and wintering elk-use sites (Cover, 2000). The initial results of these studies have already assisted the NGPC in establishing hunting season zones and harvest quotas.

Justification and Research Objectives

With the exception of the Stillings (1999) and Cover (2000) studies, little is known about critical habitat use and availability of elk habitat in Nebraska. The quality, quantity, and spatial configuration of habitat all play key roles in the amount of habitat thought to be required for elk population viability and distribution. Research is needed for wildlife managers to better understand, manage, and identify landscape-level factors that influence the suitability of elk habitat.

It is evident that Nebraska still has adequate habitat to support elk given the natural immigration of elk into the northwestern part of the state. Currently there are approximately 150-200 elk in the Pine Ridge region. Stillings (1999) and Cover (2000) found that the elk exist in two separate herds. Stillings (1999) also believes that the region can support between 500-1000 elk.

To improve overall management, wildlife biologists need to: understand why these elk are only found in two spatially disjunct areas, determine what these animals are selecting for that isn't found elsewhere in the region, identify how much of the region could be considered potentially suitable habitat, and establish the likelihood of translocating elk from the two existing herds to other potentially suitable areas in the region for the establishment of new elk herds. This thesis will explore the usefulness of combining GIS and remote sensing to answer some of the questions stated above and direct possible future efforts in modeling elk habitat.

The study evaluated the suitability of habitat for elk in the Pine Ridge region of northwestern Nebraska. The principal objectives of the study were to:

1. Identify important habitat factors based on known elk locations using GIS techniques.
2. Generate an inductive habitat suitability model using statistical techniques relating known elk locations to specific habitat characteristics.

3. Apply the model to the entire Pine Ridge region to estimate the amount and spatial distribution of potentially favorable elk habitat.

The elk of northwestern Nebraska provide a wealth of recreational opportunities for wildlife viewers, hunters, and other outdoor enthusiasts. This research has the potential to be instrumental in developing future management plans by identifying and mapping critical habitat and locating potential conflict zones between humans and elk. The results may influence future management decisions such as road closures and restricted land development in sensitive areas; land acquisition and/or conservation easements; elk displacement through land manipulation, translocation, or frightening devices; or permanent removal of elk through hunting. I designed this research to complement, evaluate, and integrate objectives and conclusions derived by Stillings (1999) and Cover (2000).

Overview of Thesis

The goal of this study was to measure elk habitat selection and develop a model to predict the suitability of elk habitat throughout the Pine Ridge region of northwestern Nebraska. The Pine Ridge study area is located in northwestern Nebraska (Figure 1). Relative proportions of elk habitat use were calculated from a set of locations of radio-collared elk (n=5,787). Elk habitat non-use was calculated from a set of random points (n=5,787). Habitat variables (landcover type, aspect, slope, distance to a road, road density, and distance from the ponderosa pine edge) were measured for each elk location and random location using GIS technology. The elk-use data for both herds was divided into 5 seasons (spring, calving, summer, rut, and winter) to determine if any seasonal variation in habitat use existed between the two herds. I used a General Linear Model

(GLM) statistical procedure to determine the significance of seasonal habitat selection intra-herd or between herds. A logistic regression model was created by comparing the habitat variable data of the elk points to the habitat variable data of the randomly generated points. I applied the model to the entire Pine Ridge study area using GIS techniques and created a map of potentially suitable elk habitat.

This thesis is organized into 5 chapters. Chapter 2 provides background information pertaining to habitat modeling, using GIS in wildlife studies, and the elk herd presently found in the Pine Ridge region. Chapter 3 focuses on the study area, GIS habitat variables used for this study, and the methodology and analysis techniques used to generate the habitat model. The results of the GIS analysis, the statistical analyses of the elk-use data, and the linear regression model developed was reported in chapter 4. Chapter 5 includes discussion of the logistic regression model findings, ways to improve the habitat modeling study, and suggested future research.

CHAPTER 2: BACKGROUND AND LITERATURE REVIEW

Introduction

Habitat modeling is a technique used to quantitatively establish species-habitat relationships and make predictions under certain management scenarios. Information on habitat use provides the foundation for model development. Geographic Information Systems (GIS) and remote sensing are modern tools that analyze spatially explicit habitat data and provide a framework for the generation of habitat models.

Evaluation of habitat for a particular species or suite of species is often conducted to assess, and, through management, improve the quality of habitat (Skovlin, 1982). Habitat assessment entails determination of the extent to which the combination of food, cover, water, and space meets the life requisites of the organism of interest. By analyzing habitat components, wildlife managers can determine the quantity and quality of available habitat for a particular species and identify areas where humans are having significant negative impacts on habitat. Managers also have the means to create comprehensive long-range management plans to improve, protect, and acquire critical habitat if necessary.

Stillings (1999) and Cover (2000) recently completed a project that generated baseline information on the Pine Ridge elk herd. The project began in 1995 using radio-telemetry and visual observations to determine: the demographics of the elk herd, effects of human disturbance on female elk, and the distribution and habitat characteristics of elk calving and winter-use areas. The results of these studies were the starting point for identifying landscape-level habitat variables influencing elk habitat selection and have potential significance in explaining areas used by elk for this project.

Habitat Modeling

One way to assess the suitability of habitat is through habitat modeling. Models are often implemented through mathematical equations that summarize data collected about a system to make predictions about habitat suitability. Such models use physical and biological attributes of a particular habitat that are meaningful to organisms of interest to yield an index of habitat suitability (Anderson and Gutzwiller, 1994). Biologists must crosswalk existing knowledge of a species' habitat requirements with landscape features that can be characterized and measured quantitatively and qualitatively.

As noted previously, a habitat model is a method for interrelating a set of physical and biological components to predict the suitability of habitat for a given wildlife species (Cooperrider, 1996). The approach taken to build this habitat model was inductive, empirical, and spatial. The inductive approach uses a sample of georeferenced species observations to identify habitat requirements from a set of resource factor maps or GIS layers (Stoms, 1992). A model is empirical in nature when it is based on field observations or laboratory data collection. A spatial model deals with spatially distributed phenomena and inter-relationships between such phenomena.

The U. S. Fish and Wildlife Service has, for example, developed a process for constructing Habitat Suitability Index models (HSI) (U. S. Fish and Wildlife Service, 1981). HSI values provide a numerical index for evaluating a particular habitat based on known habitat requirements for a given species. Biologists use existing wildlife data, pertinent literature, and expert opinion to develop an equation or algorithm that incorporates key habitat variables to predict habitat suitability (Cooperrider, 1996). HSI models attempt to mathematically describe habitat quality on a scale of 0.00-1.00, with 0.00 representing poor habitat and 1.00 representing optimal habitat. The goal is to provide an index that has a direct linear relationship to carrying capacity of a given habitat for supporting a particular wildlife species.

GIS in Wildlife Habitat Studies

Geographic Information Systems (GIS) have become increasingly important in habitat modeling and wildlife management. Numerous studies have been conducted using GIS and remote sensing techniques for habitat mapping and modeling. For example, Ormsby and Lunetta (1987) created maps of food availability for whitetail deer (*Odocoileus virginianus*) using Landsat-5 Thematic Mapper (TM) data. A previously developed habitat suitability model was used in conjunction with the TM data to determine the availability of winter and spring food types and the spatial relationship of these landcover types to escape cover. Stenback *et al.* (1987) implemented similar methods to construct a map of winter range habitat suitability for black-tailed deer (*O. hemionus columbianus*). A wildlife habitat model was developed by integrating land ownership, winter range boundaries, elevation, slope, aspect, soils, and vegetation cover types. As a result of this study, information now exists on the herd's delineated winter range that wildlife managers can use to assess habitat quality and quantity.

Forbes and Merchant (1998) combined GIS and remote sensing tools to create a habitat suitability model for bighorn sheep (*Ovis canadensis canadensis*) in the Pine Ridge of Nebraska. A combination of decision rules and deterministic equations were used in the assessment. Data layers used in the model included landcover, distance to escape terrain, distance to water, slope, aspect, and human disturbance. Habitat suitability maps that were generated from the model portrayed general habitat suitability, as well as foraging, thermal, and lambing habitat.

GIS and spatial radio-collar data were used by Mladenoff *et al.* (1995) to predict the amount and spatial distribution of favorable habitat for eastern timber wolves (*Canis lupis lycaon*) in northern Minnesota, Michigan, and Wisconsin. Regional landscape variables deemed significant in comparing pack with non-pack areas included: land ownership class, landcover type, road density, human population, fractal dimension (landcover patch boundary complexity), landcover type contagion, landscape diversity, and landscape dominance. Results indicated that wolves selected those areas that were most remote from human influence, as largely defined by low road density. Wolf pack areas also had a significantly lower fractal dimension, indicating that overall landcover patches are simpler in shape than non-pack areas.

Agee *et al.* (1989) created maps of high, medium, and low grizzly bear (*Ursus arctos*) sighting potential based on recorded grizzly bear sightings. A 22-class landcover database was analyzed using GIS to determine the landcover characteristics surrounding recorded grizzly bear sightings. The objective was to define sighting potential rather than grizzly bear habitat values. Results suggested that grizzly bears selected certain locations with similar landcover richness, but different landcover interspersion.

Homer *et al.* (1993) combined GIS and remote sensing to model Utah sage grouse (*Centrocercus urophasianus*) winter habitat using TM data. They modeled potential sage grouse winter habitat by estimating the canopy closure for each shrub class being mapped and then assessed their model with sage grouse locational data. Landowners with critical grouse winter habitat could then be identified and management efforts to minimize habitat fragmentation proposed.

Potential nesting habitat for kestrels (*Falco sparverius*) was estimated using Landsat Multi-Spectral Scanner (MSS) data and a nesting habitat model (Lyon, 1983). The model was developed from habitat requirements of kestrels in terms of landcover types and the spatial arrangement of landcover types. Data on kestrel locations were used to weight landcover types in the habitat model. The model identified areas having suitable nesting habitat. Census data revealed that seven of the ten areas that were identified as "suitable" were being used by nesting kestrel pairs.

Hodgson *et al.* (1988) inventoried and analyzed suitable wood stork *(Mycteria americana*) foraging habitat using GIS and remote sensing techniques. TM data were used to map foraging cover, while GIS was used to determine the total amount of suitable habitat, proximity of habitat to the wood stork colony, and the amount of change for a "wet" year and a "dry" year in terms of foraging habitat. The study provided a potential tool for wildlife managers to recognize the amount of foraging cover from a wet year versus a dry year and the directly related success or failure of the wood stork colony.

Herr and Queen (1993) developed a descriptive GIS model that identified potential nesting habitat of greater sandhill cranes (*Grus canadensis tabida*). A vegetation map was created from TM data and then combined with geographic data layers that included roads, buildings, and agricultural lands. The model indicated that cranes nested in potentially sub-optimal and marginal areas. Possible errors in mapping nesting habitat were identified as: problems with inherent assumptions in the data and modeling approach, unknown nesting behaviors, inability to locate all *in situ* nest sites, and inability to detect certain landscape features with satellite imagery.

GIS in Elk Habitat Modeling

Bian and West (1997) developed a logistic regression model to create a probability map of suitable elk calving sites in a prairie environment. The principal objective was to determine the relationship between observed calving sites and biophysical factors (mainly landcover types) and anthropogenic variables (roads, oil and gas wells, seep pits, and windmills). Results suggested that seep pits along the river corridor, cottonwoods (*Populus saryntii*) and salt cedar (*Tamarix ramosissimu*) shrubs in the riparian areas were statistically significant for elk calving habitat, while highways and unimproved gravel roads negatively affected elk calving habitat.

The Illinois Department of Natural Resources (IDNR) studied the feasibility of reestablishing a wild elk population in southern Illinois (Van Deelen *et al.*, 1997). A GIS-based habitat model was developed to determine the extent and configuration of potential elk habitat in southern Illinois, and to identify potential release sites. Potential elk habitat was classified as unsuitable, poor, marginal, and most suitable based on forage-cover ratios and an area-weighting function for each grid cell. The effect of road density and the spatial configuration of agricultural lands in relation to predicted suitable elk habitat ultimately persuaded the IDNR not to reintroduce elk in southern Illinois.

Sawyer (1997) evaluated a model of summer elk habitat that had been previously developed for the Bighorn National Forest (BNF) in north-central Wyoming. The model was derived from a model that Wisdom *et al.* (1986) created to evaluate elk habitat in western Oregon. Variables included road density, size and spacing of forage/cover areas, cover quality, and slope. The model was validated using locations of radio-collared elk. When comparing the locational data to the model output it was concluded that elk were more sensitive to road density and slope than predicted by the model. The model was then adjusted to better define elk-habitat interactions and more likely to reflect actual elk use.

Huber (1992-93) integrated remote sensing and GIS techniques to identify and map critical habitat zones where elk and humans interact and compete for limited space. Elk movement was first analyzed by radio-tracking ten female elk. Elk habitat was mapped using TM data to create a 13-class vegetation layer (Huber and Casler, 1990). Land use/zoning maps were analyzed in conjunction with the elk home range data and the vegetation layer to delineate areas of current critical elk habitat and future human land development. Results suggest that even though the area contains a large amount of available habitat, only the prime habitat is being used due to human disturbance.

Elk Habitat Variables

Considerable research has been conducted on the suitability and effectiveness of habitat for elk in the Northwestern Rocky Mountain region of the United States (Thomas *et al.*, 1979, 1988a, 1988b; Lyon, 1979, 1983; Bright, 1981; Leckenby, 1984; Leckenby *et al.*, 1985; Witmer *et al.*, 1985; Wisdom *et al.*, 1986; Adams and Edwards, 1987; Brunt, 1990; Sawyer, 1997). The effectiveness of elk habitat is the ability of an area to meet elk growth and welfare requirements. The primary habitat factors that limit elk populations are forage, cover, and water (Thomas *et al.*, 1979).

Thomas *et al.* (1979) defined optimum elk habitat in the Blue Mountains of Oregon and Washington as "the amount and arrangement of cover and forage areas that result in the maximum possible use of the maximum possible area." They classified elk habitat effectiveness based on the relationships and interactions of three habitat variables. The first variable was size and spacing of forest cover and forage areas. The optimum size of cover and forage areas can be projected as a ratio in which 40% of the landtype is cover and 60% of the landtype is forage. Forage areas should be located no farther than 183 m (600 ft) from the cover edge for maximum foraging use. The second variable was habitat quality (hiding and thermal cover). Hiding cover was defined as "vegetation capable of hiding 90% of a standing adult deer or elk from the view of a human at a distance equal to or less than 61 m (200 ft). Thermal cover for elk was defined as "any stand of coniferous trees 12 m (40 ft) or more tall, with an average canopy closure exceeding 70%." The final variable was road density. Lyon (1983) further refined the relationship between habitat effectiveness and road density based on pellet-group and telemetry data collected in Washington and Oregon.

Wisdom *et al.* (1986) and Thomas *et al.* (1988a) developed a model to evaluate habitat effectiveness in western Oregon based on the elk habitat criteria defined earlier by Thomas et al. (1979), Lyon (1983), and Witmer *et al.* (1985). The model evaluates elk habitat based on the interactions of four variables: 1) sizing and spacing of forage and cover, 2) cover quality, 3) forage quality, and 4) density of roads open to motorized vehicles.

Seasonal Distribution and Habitat Characteristics of Elk in Nebraska

Stillings (1999) and Cover (2000) identified two distinct study areas in the Pine Ridge from the annual home ranges of 21 radio-marked female elk. One herd was located east of Chadron, Nebraska in the Bordeaux Creek study area; the other herd was located west of Crawford, Nebraska in the Hat Creek study area (Figure 2). These elk were radio-tracked for 5789 elk-days from April 1995 to August 1997.

Stillings (1999) and Cover (2000) identified four human disturbance variables that influenced habitat selection by female elk, based on home range data. Timber harvest and associated hauling activities were found to temporarily displace elk. Elk home ranges shifted an average 5554 m away from active timber harvest, versus the home range shift of 3337 m of elk not exposed to timber harvest, over the same time period. Elk responded to the presence of alfalfa, oats, and millet during the summer by reducing and shifting home ranges approximately 2.5 km toward crop production areas. The shift coincided with the maturation of oats and millet during the late dough-stage and the second cutting of alfalfa. It was also noted that the elk did not necessarily shift to the closest agricultural fields, but rather moved towards those fields in proximity to hiding cover.

The Bordeaux Creek herd shifted home ranges an average of 4952 m toward winter wheat fields and toward a NGPC feeding ground during the winter months. To reduce elk depredation to privately owned crops, the NGPC provided alfalfa to deer and elk from November to March. The Hat Creek herd did not have access to a feeding ground and did not use winter wheat fields, instead selecting grassland and forested habitats during the winter months. The stocking of cattle into pastures had significant effects on resident elk. The presence of cattle resulted in elk moving out of recently stocked pastures and reduced the size of elk home ranges. The stocking of cattle also coincided with elk calving seasons and may have negative impacts on calving site radio-telemetry data obtained from these studies it was also determined that no movement of elk between the two herds exists and the herds are functioning as separate populations and not a metapopulation.

Summary

Habitat modeling is one way to predict suitability on a regional scale based on very local species-habitat relationships. Geographic Information Systems are tools that have become very important of late in modeling and mapping habitat suitability quickly and efficiently. Considerable research has been conducted on elk habitat use in the northwestern Rocky Mountain region and more recently on elk in northwestern Nebraska. The results of these research projects were instrumental in determining which geographic habitat variables could potentially be significant in explaining elk habitat use in the Pine Ridge region of northwestern Nebraska.

CHAPTER 3: METHODS

Introduction

The goal of this study was to measure elk habitat selection and develop a model to predict elk habitat suitability throughout the Pine Ridge region of northwestern Nebraska. Habitat selection was inferred from telemetry data of radio-collared female elk ($n = 5,787$ dating from April 1995 to August 1997) using GIS technology. Habitat variables (landcover type, aspect, slope, distance to a road, road density, and distance from the ponderosa pine edge) were measured for each elk and random location. The elk-use data for both herds was divided into 5 seasons (spring, calving, summer, rut, and winter) to determine if any seasonal variation in habitat use existed between the two herds. I used a General Linear Model (GLM) statistical procedure to determine the significance of seasonal habitat selection intra-herd or between herds. A logistic regression model was created by comparing the habitat variable data of the elk points to the habitat variable data of the randomly generated points.

Study Area

The Pine Ridge is located in northwestern Nebraska (Figure 1). Forests and savannas of ponderosa pine dominate the rugged escarpments and hills. Species of trees associated with canyon bottomlands and riparian areas commonly include American elm (*Ulmus americana*), cottonwood (*Populus deltoides*), green ash (*Fraxinus pennsylvanica*), and hackberry (*Celtis occidentalis*). Predominate grass species found on exposed ridges and amongst the savanna trees include big bluestem (*Andropogon gerardii*), little bluestem (*Schizachyrium scorparium*), and sand bluestem (*Andropogon hallii*) (Kaul and Rolfsmeier, 1993).

The Pine Ridge is characterized by a mix of federal, state, and private land ownership (Figure 1). Sparsely populated rural areas consisting of farms and ranches dominate the landscape with occasional small towns comprising the urban areas. Road densities are generally low with most being unpaved county roads. Only two major state highways traverse the study area. Average annual precipitation for the area is 46 cm, with the majority falling in May and June. Elevations range from 940 m to 1590 m. Landuses for the area include livestock grazing, logging, alfalfa and small grains production, and a variety of recreational activities.

The study area is approximately 489,113 ha. The boundary follows U. S. Geological Survey (USGS) 7.5-minute topographic quadrangle boundaries (1:24,000 scale). The study area boundary encompasses most of the pine-covered escarpments associated with the Pine Ridge and all of the elk locational point data generated from the Stillings (1999) and Cover (2000) studies.

GIS-Based Model Data Layers

Elk Location Data

Stillings (1999) and Cover (2000) radio-tracked 21 female elk from April 1995 to August 1997. The location data obtained from the radio-collared female elk identified two distinct herd areas in the Pine Ridge. One herd area is located east of Chadron, Nebraska (the Bordeaux Creek herd), while the other is located west of Crawford, Nebraska (the Hat Creek herd) (Figure 2). From 1996 - 1999, 70 - 100 elk could be found in each of the herd areas. Geographic habitat variables (landcover type, aspect, slope, distance to a road, road density, and distance from ponderosa pine edge) used in this study were based on the results of Stillings (1999) and Cover (2000), as their research was specific to elk and habitat components found in the Pine Ridge area.

Elk in the Bordeaux Creek area were located 3,011 times and elk in the Hat Creek area were located 2,776 times. A vehicle-mounted, 9-element Yagi antenna was used to obtain elk most locations. Elk locations were determined by triangulating the direction of the radio-transmitter signal. Fixed receiver locations (road intersections) were used to help locate the elk. To ensure a true representation of elk movements, telemetry locations were obtained at different times of the day. Elk locations were also recorded by visual observations of collared elk and ground tracking using a 3-element Yagi antenna or a 2-element H-antenna.

Elk locations were georeferenced using the Universal Transverse Mercator (UTM) coordinate system. The data were imported into ArcInfo to create a point coverage attributed with elk identification number and date of acquisition. The point coverages for each herd were then divided into five seasonal coverages to measure the potential seasonal differences in elk habitat selection. The seasonal breakdown consisted of the following dates: spring (March 14-May 14), calving (May 15-June 30), summer (July 1-August 31), rut (September 1-October 31), and winter (November -March 13).

Landcover

A landcover map of the study area was produced using Landsat TM imagery (path 33, row 30, 28.5 m resolution) obtained from the USGS EROS Data Center. The TM scenes were resampled to 30 m pixel resolution to be consistent with the pixel size of other GIS data layers. Three dates from the 1997 growing season were used: spring (05-09-1997), summer (06-26-1997), and fall (09-30-1997). These dates provided ample temporal differences in seasonal plant phenology and hence sufficient spectral separation among landcover classes to generate a map.

Supervised digital image processing techniques were used to generate a map with 12 landcover classes (Jensen, 1996) (Table 1). The vegetation classification scheme was based on dominant vegetation types, land use practices for the area, and results of the Stillings (1999) and Cover (2000) studies which documented the influence of agricultural crop production on female elk foraging habits in the Pine Ridge region and the affect of ponderosa pine forest on elk calving areas. Supervised classification training sites were obtained through a combination of analysis of aerial photography, personal experience, National Wetland Inventory (NWI) data, and a previously completed Cooperative Hydrology Study (COHYST) that created a detailed map of 1997 land use and landcover for the Platte River Basin. The training sites chosen were representative, homogeneous examples of the landcover classes of interest. There was enough overlap between TM scenes of the COHYST and this study that I was able to obtain agriculturally related and riparian woodland training sites from the COHYST classification and apply this to my study area classification. A 3x3-majority filter was applied to the classified imagery to remove some of the salt-and-pepper effect of confused or misclassified pixels scattered throughout the scene. The classified TM scene was then clipped to the study area boundary. Fieldwork was not done to determine landcover classification accuracy due to the time lag of when this classification was completed (2000) and the date in which the imagery was obtained (1997).

To compare landcover data available to each herd and herd area size, a 1-km buffer was generated around the Bordeaux Creek and Hat Creek herd location points.

Landcover data amounts were then calculated for the areas inside of each polygon created by the 1-km buffer. Habitat use (selection) can then be compared to habitat availability to determine if one landcover type is being selected more than another based on availability.

Distance to a Road

A road coverage was acquired from USGS Digital Line Graph (DLG) data (1:100,000 scale). The coverage was clipped to the study area boundary and converted to a grid in ArcInfo with a cell size of 30 m. A Euclidian distance function was applied to the grid, generating a new grid representing distance to the nearest road at every pixel location throughout the entire study area.

Road Density

A second road grid was created from the same DLG road data (1:100,000 scale). A moving circular window (area equivalent to 1 km^2) was used to sum all "road pixels" within the window. The value of the summed "road pixels" was then assigned to the center pixel. Road density for the entire study area was calculated on a pixel-by-pixel basis. The grid had 30 m pixel resolution and was clipped to the study area boundary.

Aspect and Slope

A seamless Digital Elevation Model (DEM) for the state of Nebraska was aquired from USGS. The source data were 7.5 minute DEMs (1:24,000 scale). The DEM was converted to a grid in ArcInfo, reprojected, and resampled to 30 m pixel resolution. The DEM was then clipped to the study area boundary and the ArcGrid functions for slope and aspect were applied. Aspect was expressed as positive degrees from 0-360 with 360° being north and slope expressed as degrees from 0-90 with 90° being vertical.

Distance from the Ponderosa Pine Edge

Initially the landcover data were separated into two grids. The first grid contained both pondersosa pine classes (ponderosa pine > 70% canopy closure and ponderosa pine 40-70% canopy closure), which were recoded into one landcover class representing "cover areas." The second grid contained the remaining landcover types, which were recoded into the other landcover class representing "forage areas." A Euclidian distance function was applied to each grid calculating, respectively, distances into cover areas and distances into forage areas. The two grids were then overlaid to create one grid representing continuous distances into cover areas from the ponderosa pine edge and distances out into forage areas away from the ponderosa pine edge.

Elk Habitat Use Data

To assess elk habitat selection, all elk point locations were analyzed in conjunction with each GIS layer. To reduce the time needed to analyze the elk point locations in relation to the six GIS layers, the layers were combined into one layer with multiple attributes describing every pixel location. An Arc Macro Language (AML) program was written to analyze every elk point location in relation to the combined GIS layer. An output file with six habitat variables for every elk point location was generated. For example, the location of elk #1 on January 01, 1995 might have an output of: landcover, ponderosa pine (>70% canopy coverage); aspect, 90°; slope, 10°; distance to a road, 150 m; road density, 0.95 km/km^2; and distance from the ponderosa pine edge, 50 m.

The elk-use data for both herds were divided into 5 seasons (spring, calving, summer, rut, winter) to determine seasonal habitat selection differences. A GLM statistical procedure was used to determine significant seasonal habitat selection differences intra-herd or between herds. The GLM procedure tested for mean differences (SAS, 1999). An example would be testing for mean seasonal habitat selection differences of slope values between the Bordeaux Creek herd calving season and the Hat Creek herd calving season.

Initially, the Analysis of Variance (ANOVA) technique was selected to compare means of elk habitat use between seasons and herds. The GLM procedure was used instead because of its functionality with unbalanced data sets. Basic statistical assumptions underlying GLMs are that the data are normally distributed and have minimum variance (SAS Institute Inc, 1999). The assumption of normality is required by the GLM procedure to make all calculated significance levels (p values) and confidence limits valid (SAS Institute Inc, 1999). The GLM can be viewed as an extension of linear multiple regression analyzing one or more continuous dependent variables to one or more independent variables (SAS Institute Inc, 1999). The GLM procedure uses the method of least squares estimation to fit general linear models (SAS Institute Inc, 1999).

A log transformation was applied to the data to normalize and reduce data skewness. This transformation allowed for the calculation of geometric means rather than the arithmetic means for the entire data set. The geometric mean is a measure of central tendency and obtained by calculating the average of the n^{th} root of a set of n numbers (SAS Institute Inc, 1999). The GLM tested linear combinations of predictor variables (i.e. GIS habitat variables) to test geometric mean differences in elk habitat use. The geometric mean is useful in comparing habitat use for this study by reducing the effect of extreme high and low values (outliers) which may skew data representation.

Random Points

To validate differences, if any, of elk-use areas versus non-use areas, a set of randomly generated points were compared with the actual elk point locations. It was assumed for the purpose of this study that the entire study area was potentially suitable elk habitat. The NGPC has defined the Pine Ridge of western Nebraska as desirable elk habitat where they will actively manage for a self-sustained elk population (Menzel, K., NGPC, Pers. comm.). The only areas excluded from this analysis were urban areas within the study area boundary. Urban areas were defined as unsuitable habitat due to the presence of humans.

An Arcview script was used to generate 5,787 random points within the study area boundary. The number of random points equaled the number of total elk locations. The same AML program used for the elk point locations was used to extract the six habitat variables for every randomly generated point.

Elk Habitat Model Development

I used logistic regression to create a model evaluating regional habitat suitability for elk in northwestern Nebraska. It is a type of regression that is used when the dependent variable is a binomial (i.e. elk-use versus non-use) and the independents are continuous variables, categorical variables, or both (i.e. GIS habitat variables) (SAS Institute Inc, 1999). Logistic regression predicts the probability of occurrence as a function of the independent variables, i.e., the probability of elk presence given particular habitat variables for that location (SAS Institute Inc, 1999). The logistic regression procedure fits linear logistic regression models by the method of maximum likelihood estimation (SAS Institute Inc, 1999). The logistic procedure in SAS has an additional option in the model building process controlling how to move variables in and out of a model (stepwise selection) (SAS Institute Inc, 1999). Effects (variables) can enter or leave a model using the stepwise selection in a single step based on predetermined p-values. This modeling technique has been used in similar wildlife habitat studies (Pereira and Itami, 1991, Mladenoff *et al.*, 1995, Bian and West, 1997, Mladenoff and Sickley, 1998, Stillings, 1999, Cover, 2000).

The landcover classes riparian woodland, lowland tall grass prairie, other agriculture, barren/sand/rock outcrop, wetland, and open water were not included in the model building process because of low frequency of occurrence. The rest of the geographic habitat variables (landcover types including ponderosa pine (>70% canopy closure), ponderosa pine (40-70% canopy closure), western mixedgrass prairie, small grains agriculture, fallow agriculture, alfalfa/hay; aspect; slope; distance to a road; road density; and distance from the ponderosa pine edge) were entered into a stepwise logistic regression analysis (SAS Institute Inc, 1999). This analysis generated a model whose output values range from 0 - 1, with 0 representing 0 % probability of potential elk habitat and 1 representing 100 % probability of potential elk habitat given the initial input parameters (i.e. GIS habitat variables).

The regression coefficients generated by the modeling process were applied to each GIS habitat layer variable. The final GIS layer was then composed of grid cells expressing habitat suitability values for the entire study area. These habitat suitability values were then recoded into 4 habitat suitability classes. Grid cells that had values between 0.0 - 0.25 received a 1 (low suitability), 0.26 - 0.50 received a 2 (medium suitability), 0.51 - 0.75 received a 3 (high suitability), and 0.76 - 1.0 received a 4 (optimal suitability).

Summary

Elk habitat selection was determined from telemetry data of radio-collared female elk in northwestern Nebraska. Landcover type, aspect, slope, distance to a road, road density, and distance from the ponderosa pine edge were measured for each elk and random location. I used a GLM statistical procedure to determine intra-herd and inter-herd significant habitat selection differences. A randomly generated point coverage was created and compared with the elk point locations to validate differences, if any, between elk-use and non-use areas. I used a logistic regression procedure to create a model evaluating regional habitat suitability.

CHAPTER 4: RESULTS AND DISCUSSION

Introduction

Habitat modeling is one way to assess habitat selection and predict suitability on a regional scale. Elk habitat preference in the Pine Ridge region was determined from a set of radio-collared elk locations and compared to a randomly generated point coverage. Landcover type, aspect, slope, distance to a road, road density, and distance from the ponderosa pine edge were measured for each elk and random location to compare elk-use and non-use areas. The elk-use data for both herds were also broken down into 5 seasons (spring, calving, summer, rut, and winter) to determine if any seasonal variation in habitat use existed between the two herds. By integrating statistical techniques and GIS, a logistic regression habitat model was developed describing the spatial and temporal component to elk habitat selection.

GIS-Based Model Data Layers

Landcover

Satellite imagery was used to create a 12-class landcover map of the study area (Figure 3). Landcover percentages ranged from 66% (323,956 ha) of the study area classified as western mixed grass prairie to 0% (426 ha) classified as wetland and open water when compared to the entire study area (Figure 4).

To compare inter-herd landcover data and herd area size, a 1-km buffer was generated around the Hat Creek and Bordeaux Creek herd location points (Figure 5). Landcover amounts available to each herd differed significantly as did the size of the herd areas. The Bordeaux Creek herd area was 46,868 ha in size and consisted of approximately 8% ponderosa pine (>70% canopy coverage), 31% ponderosa pine (40-

70% canopy coverage), 44% western mixedgrass prairie, 9% agricultural crops, and 6% alfalfa (Figure 4). The Hat Creek herd area was 42,777 ha in size and consisted of approximately 8% ponderosa pine (>70% canopy coverage), 16% ponderosa pine (40-70% canopy coverage), 67% western mixedgrass prairie, 2% agricultural crops, and 5% alfalfa (Figure 4).

Elk location point data illustrated some differences between seasons and herds when selecting certain landcover types. When neglecting the seasonal component of habitat use, the Bordeaux Creek herd locations were found primarily in areas classified as Ponderosa Pine (40-70% canopy coverage) (38%) and western mixedgrass prairie (39%) (Figure 6). Contrarily, the majority of the Hat Creek herd locations were found in areas classified as western mixedgrass prairie (48%) (Figure 6). To gain more insight into elk habitat selection, habitat use versus availability could be measured and quantified to determine if selection is actually significant. These measurement procedures were not conducted for this study, but could be the potential topics for future studies.

Both herds exhibited some seasonal differences in habitat preference. The majority of the spring (45%), calving (57%), summer (45%), and rut (50%) locations for the Bordeaux Creek herd were found in Ponderosa Pine (40-70% canopy coverage) (Figure 7). Western mixedgrass prairie was the major landcover type preferred in the winter (57%). This was probably due to the NGPC feedground being located in an area classified as western mixedgrall prairie. The majority of the spring (45%), summer (43%), rut (50%), and winter (53%) locations for the Hat Creek herd were found in western mixedgrass prairie (Figure 8). Ponderosa Pine (40-70%) was the major landcover type preferred during calving season (42%). Stillings (1999) found that elk calving areas were located in ponderosa pine forest 73% of the time.

Skovlin (1982) and Thomas *et al.* (1979) agree that two of the basic habitat requirements for elk survival are cover and food (forage). Cover is often associated with coniferous forests in the western U.S. and mixed conifer-hardwood forests in the eastern U.S. Cover in the Pine Ridge region is predominately ponderosa pine forest and savanna. Forage found in North America is extremely variable, often dictated by the vegetational environment, season, year, individual preference, and availability (Nelson and Leege, 1982). Forage for elk in the Pine Ridge includes western mixedgrass prairie, agricultural crops, and forage crops such as alfalfa and hay.

Elk in the Pine Ridge clearly indicate a strong preference for ponderosa pine (both classes). The ponderosa pine forest may be providing hiding cover, thermal cover, or a combination of the two to satisfy elk requirements. Hiding, thermal, and optimal covers are distinct types of habitat widely recognized as important for elk survival.

Until recently, wildlife biologists agreed that the energetic benefit of dense forest canopies moderating harsh weather conditions is highly important to deer and elk. Cook *et al.* (1998) questioned this theory and found evidence that there is no significant positive affect of thermal cover on the condition of elk and that dense cover may actually be the more costly energetic environment. He further states that the primary mechanisms affecting elk performance are quality, quantity, and distribution of forage in relation to thermal cover.

Aspect

Aspect was computed for the entire study area and ranged from 0-359° (Figure 13). Percentages for aspect were distributed somewhat evenly when divided by class for the study area, but the majority (28%) of the study area fell into the 315-45° quadrant (Figure 14).

When neglecting the seasonal component for each herd, the locational data percentages were almost identical between the herds when split into 4 cardinal quadrants. The majority of the Bordeaux Creek (31%) and Hat Creek (31%) locations were found in the aspect range of 315-45° (Table 2). While the minority of the Bordeaux Creek (14%) and Hat Creek (17%) locations were found in the aspect range of 135-225° (Table 2).

The seasonal preference of aspect mimicked that of the locations above, with both herds preferring primarily the same aspects during the same season. Seasonally, the majority of the Bordeaux Creek elk locations had an easterly aspect in the spring and summer, westerly aspect during calving, and northerly aspect during rut and winter. The majority of the Hat Creek elk locations had an easterly aspect in the spring and a northerly aspect during calving, summer, rut, and winter. The minority of all elk locations (Bordeaux and Hat Creek) for all seasons (spring, calving, summer, rut, and winter) had a southerly aspect.

Factors largely affecting the seasonal use of aspect are forage availability, thermoregulation, and cover type (Skovlin, 1982). Unsworth *et al.* (1998) found that female elk typically could be found on south-facing to west-facing aspects on winter range in Idaho. Elk in the Pine Ridge region were primarily found on west-facing aspects in the winter. Elk in Oregon selected for westerly aspects in the spring (Johnson, 2000). Spring elk locations in northwestern Nebraska had an easterly aspect.

Slope

Slope for the entire study area ranged from 0-54.5° (Figure 15). The majority (86.7%) of the study area was in the 0-10° slope class (Figure 16). Annually, the Bordeaux Creek herd preferred areas with gentler slopes (μ=8.42°) than the Hat Creek herd (μ=11.18°) (Table 2). Seasonally, the Bordeaux Creek elk preferred areas with steeper slopes during calving season (μ=9.12°) and gentler slopes during the winter (μ=7.10°). Stillings (1999) found steeper slopes to be significant in explaining elk calving areas. The slope of the NGPC feedground could have greatly influenced the gentler winter slope values. The Hat Creek elk selected steeper slopes in the spring (μ=12.11°) and gentler slopes during the rut (μ=9.72°).

The preference of certain slopes by elk may be determined by microclimate, plant composition, decreased accessibility of humans due to steepness, and ease of movement by using upper slopes and ridge tops for travel lanes (Skovlin, 1992). Skovlin (1982) denotes that as slope steepness increases to a maximum of 30-40%, so does elk use. He further explains that slopes in the 15-30% range seem to be the most frequently used. Elk in Wyoming on the BNF preferred slopes between 10-30%, with elk use quickly decreasing with slopes over 30% (Sawyer, 1997). Stillings (1999) found that the average slope of elk calving sites was 11°, and that the sites were often surrounded by steeper slopes (range = 12-29°).

cover is thought to reduce vulnerability of calves to predation. Elk selecting areas close to the forest edge during the winter might provide a readily accessible forage source along with the added benefit of adjacent security cover that elk could quickly enter to escape predation. Maximum foraging intake and the least amount of energy expenditures occurs when forage and cover areas are of appropriate size and in proximity (Wisdom *et al.*, 1986).

Witmer *et al.* (1985) stated that the majority of elk-use occurs within 100 yds of the edge in forage areas and within 300 yds of the edge in cover areas. The only exception to this is when cover areas are not large enough to exceed 100 yds from the edge (or 200 yds in width). Elk in Wyoming selected areas along the forage-cover edge based on habitat effectiveness model results (Sawyer, 1997) and elk in Nebraska calved on average < 300 m from the edge of 2 habitat types (Stillings, 1999). Leckenby (1984) found that in the summer and winter, elk-use of thermal cover areas were within 400 yds of the forage edge nearly 100% of the time. He also found that elk-use of forage areas was within 500 yds of the cover edge more than 80% of the time.

Elk Habitat Use Data

When neglecting the seasonal component of habitat use between the two herds, statistical significance of habitat preference varied when computed using the GLM procedure. Differences in habitat preference for slope and distance from the ponderosa pine edge were all found to be statistically significant when comparing the geometric means of the Bordeaux Creek herd to the Hat Creek herd with a significance level of 0.05. Habitat variables not found significantly different when comparing the elk-use data of the two herds were road density and distance to a road ($p>0.05$). When a p-value is greater than the significance level (i.e. 0.05), one can conclude that the variable is not stastically significant. In contrast, when the p-value is lower than the significance level (i.e. 0.05), one can conclude that the variable tested is stastically significant. Landcover and aspect were not entered into the GLM procedure because of the categorical nature of the landcover data and interval nature of the aspect data.

The slopes that were preferred by elk were significantly different ($p<0.05$) between both herds during the spring, calving, summer, and winter seasons. The rutting season was the only time period when preferred slopes were similar between herds. The values measured for the habitat variable "distance to a road" differed significantly for the spring and summer seasons between the two herds. Elk habitat preference among seasons and herds did not differ significantly during the calving, rut, and winter seasons regarding distance to a road. The spring season was the only time period when habitat preference among seasons and herds differed for road density values. Road density measurements were not different for calving, summer, rut, and winter seasons. The calving, summer, rut, and winter seasons were all deemed significant for the "distance into forage" habitat variable. The spring season was not different regarding distance into forage. The "distance into cover" habitat variable was unique in that all 5 seasons had statistically significant selection differences between the two herds.

Random Points Data

Random points (n=5787) were generated to quantify differences in elk habitat preference between elk-use and non-use areas (Figure 19). Every random point location was analyzed in relation to 6 GIS layers (landcover, aspect, slope, distance to a road, road density, and distance from the ponderosa pine edge) to obtain elk non-use habitat data.

The random points ideally could not be divided by season, hence the random points were compared to all elk locations (Bordeaux and Hat Creek herd locations pooled).

The majority (31%) of all random points had an aspect of 315-45°, which was identical to the majority (31%) of all elk point data having an aspect of 315-45° (Table 3). The random points had an average slope of 5.18° compared to an average slope of 9.52° for the elk points (Table 3). The random points were found closer to a road (μ=454 m) than the elk point data (μ=529 m) (Table 3). The random points were located in areas with higher road densities (μ=0.95 km/km^2) than the elk points (μ=0.73 km/km^2) (Table 3). Finally, the random points were found farther from the ponderosa pine edge (μ=474 m) than the elk points (μ=90 m) when in forage areas and closer to the ponderosa pine edge (μ=14 m) than the elk points (μ=48 m) when in cover areas (Table 3).

Compared to the random point habitat data, the elk point habitat-use data on average had greater slopes, were farther from the nearest road, had lower road densities, were closer to the ponderosa pine edge when in forage areas, and were farther from the ponderosa pine edge when in cover areas. The elk points were also found in areas classified as ponderosa pine forest the majority of the time. These conclusions generally agree with most of the published literature identifying environmental phenomena significant in explaining elk-use areas.

Elk Habitat Model

Logistic Regression Model

Habitat selection differed significantly between herds and among the seasonal periods. To achieve the goal of this study, seasonal and herd differences in habitat selection were ignored. The elk locations in the Bordeaux and Hat Creek areas were pooled and the seasonal component of the study was dropped. Thus, all elk locations (elk-use) were compared to the random point locations (elk non-use). Multiple models could have been generated for each season and herd, but the goal of this study was to develop one model representative of all elk in the Pine Ridge region and to apply that model to the entire study area using GIS techniques to produce a habitat suitability map.

A logistic regression model was developed to describe elk habitat selection for two discrete, non-migratory elk herds in the Pine Ridge region. Slope, distance to a road, road density, distance from the ponderosa pine edge and landcover types including ponderosa pine (>70% canopy coverage), ponderosa pine (40-70% canopy coverage), western mixedgrass prairie, and alfalfa were habitat variables found to be statistically significant in explaining elk use areas. Habitat variables not deemed statistically significant were aspect and the landcover types small grains agriculture and fallow agriculture. The logistic regression model is represented by the following equations:

$$
\begin{aligned}
Y = 0.1621 \\
&+ 0.9449 \text{ (ponderosa pine (>70\% canopy coverage))} \\
&+ 0.6141 \text{ (ponderosa pine (40-70\% canopy coverage))} \\
&+ 0.1932 \text{ (western mixedgrass prairie)} \\
&+ 0.6436 \text{ (alfalfa/hay)} \\
&+ 0.0667 \text{ (slope)} \\
&- 0.00066 \text{ (distance to a road)} \\
&- 0.2839 \text{ (road density)} \\
&- 0.0025 \text{ (distance from the ponderosa pine edge)}
\end{aligned}
$$

and

$$P = e^{Y} / (e^{Y} + 1)$$

where P is the estimated probability of suitable elk habitat at a particular location and Y is the exponent of the logistic regression equation.

According to the model, the presence of the landcover types ponderosa pine (>70% canopy coverage), ponderosa pine (40-70% canopy coverage), western mixedgrass prairie, and alfalfa/hay increased the probability of suitable elk habitat with ponderosa pine (>70% canopy coverage) receiving the highest weight. Woodland habitat (ponderosa pine forest) in the Pine Ridge reduces the effects of human disturbance on elk distributions. Types of disturbance found in the area include timber harvest, agricultural crop production, cattle production, roads, and farmsteads. Stillings (1999) found that female elk selected areas for calving with slightly more overstory canopy coverage and more hiding cover than randomly located sites. Stillings (1999) also found that during the summers of 1995-1997, elk distribution was affected by the presence of alfalfa, oat, and millet fields. Elk fed on these crops and subsequently shifted their home ranges toward these fields.

A location's probability for suitable elk habitat also increased as the slope increased according to the model. Similarly, Skolvin (1982) found that as slope steepness increases to a maximum, so does elk use. The rugged topography (steep slopes) of the Pine Ridge is selected for by elk probably due to the decreased accessibility by humans.

The negative regression coefficients of distance to a road, road density, and distance from the ponderosa pine edge indicated that smaller values or shorter distances tended to increase suitable elk habitat probabilities. Stillings (1999) stated that elk response to roads is related to past experience, acclimation, season, and associated habitat. The Bordeaux Creek elk in particular were not affected by one of the busiest highways in northwestern Nebraska during the winter (Stillings, 1999). But, when comparing the elk locations to the random locations, evidence was found that elk were preferring areas with lower road densities and avoiding areas adjacent to roads. Elk locations were also found in areas closer to the forest edge than would be expected randomly.

GIS techniques were used to apply the model to the entire study area and create a map of potentially suitable elk habitat (Figure 20). The results of the logistic regression model suggest that the amount of suitable habitat in the study area ranges from low (34%), medium (38%), high (21%), and optimal (8%). The highest probabilities of suitable habitat tend to mimic the landcover classes of ponderosa pine (>70% canopy coverage) and ponderosa pine (40-70% canopy coverage). A definite distance out (buffer) from the ponderosa pine areas is also visually discernible (Figure 20) which is likely due to the "distance from the ponderosa pine edge" habitat variable coefficient.

Summary

Elk habitat preference differed among seasons and herds. Geographic habitat variable data also differed when comparing the elk habitat data to the random point habitat data. To generate the logistic regression model, both the Bordeaux and Hat Creek locations were pooled and the seasonal component dropped. Habitat preference differences between the elk points and the random points were calculated. Slope, distance to a road, road density, distance from the ponderosa pine edge and landcover types including ponderosa pine (>70% canopy coverage), ponderosa pine (40-70%

canopy coverage), western mixedgrass prairie, and alfalfa were habitat variables found to be statistically significant in explaining elk use areas. Habitat variables not deemed statistically significant were aspect and the landcover types small grains agriculture and fallow agriculture.

CHAPTER 5: CONCLUSIONS

Introduction

Suitable elk habitat continually decreases as humans settle and develop the western U.S. The Pine Ridge region is following this trend as people are purchasing property in the area due to the unique, rugged, ponderosa pine escarpments given the surrounding rolling hills and plains. Elk in the Pine Ridge region also thrive because of this uniqueness and of the decreased elk-human interaction due to the relatively small population of farmers and ranchers. With the influx of people into the region, potential for elk-human conflicts will dramatically increase. Wildlife managers need to identify habitat selection and distribution of elk to determine potentially suitable areas that in the future could be used for establishing new elk herds elsewhere in the region.

Logistic Regression Findings and Implications

A logistic regression model predicting potential elk habitat suitability was developed for the Pine Ridge region of northwestern Nebraska. GIS technology was used to measure elk habitat selection from a point coverage and six spatially concurrent habitat variable data layers. Landcover type, aspect, slope, distance to a road, road density, and distance from the ponderosa pine edge were measured for each elk location to help explain habitat use areas. The habitat variables were also measured for a randomly generated point coverage to compare and contrast the differences, if any, between elk-use and non-use areas. By comparing the habitat variable data of the elk points to the habitat variable data of the randomly generated points, a logistic regression habitat model was created.

The NGPC is managing the Pine Ridge elk herd by implementing annual hunting seasons every fall. Population management (hunting) is currently the most cost effective means of reducing and managing elk numbers. The goal of the NGPC is to reduce and sustain elk population levels to a point that is socially acceptable to the region's farmers and ranchers. Elk depredation to agricultural cropland and forage production can lead to significant reductions in grain yield and forage biomass.

Exactly how many elk the Pine Ridge region can sustain ecologically and socially is a question that has yet to be answered. Presently there are 150-200 elk in the Pine Ridge. The current NGPC elk management plan calls for maintaining a minimum population of 100 elk in the Pine Ridge. Stillings (1999) believes that the area can support between 500-1000 elk. The results of this regional GIS-based habitat suitably study indicate that the Pine Ridge region is composed of 140,000 ha (540 mi^2) of potentially high-to-optimal suitable elk habitat. It appears from this study that the Pine Ridge region can support more elk than currently are found there and that the NGPC should review these results and perhaps revise it's management plan.

The majority of elk found in the region occur on private land. This poses increased challenges to wildlife managers. Elk may use these private lands as refuges that are in some instances closed to hunting. Elk use of private land may be temporary, as with elk finding security during hunting seasons, or year-round which greatly increases the likelihood of management problems. Regardless of the amount of potentially suitable elk habitat predicted by the model for the Pine Ridge region, elk population and distribution will be driven by the social attitudes of local farmers and ranchers.

The results of this study suggest that there is abundant potentially suitable elk habitat located throughout the region. Optimal habitat suitability areas are located adjacent to each herd and spatially contiguously between the two herds. What is keeping these elk from moving into adjacent suitable habitat or moving between herds is not currently known. By identifying key habitat variables and other potentially suitable areas in the Pine Ridge region, wildlife managers have the means for locating and acquiring areas in which future elk herds may become established if warranted.

Ways to Improve Elk Habitat Suitability Study

Elk require large areas of suitable habitat for continued existence. Mean home range sizes of female elk in the Pine Ridge region ranged from 681 ha to 4233 ha before, during, and after four environmental periods (logging, second cutting alfalfa, feedground usage, and cattle stocking), 1995-1997 (Stillings, 1999). The majority of habitat required by elk needs to be in the form of large, contiguous forested areas. The landcover map created for this study had many small groups of extraneous ponderosa pine (ponderosa pine >70% canopy closure and ponderosa pine 40-70% canopy closure) pixels scattered throughout the study area. By analyzing Figure 20 one can see these scattered pixels throughout the study area as circles of medium to high habitat suitability surrounded by areas of low habitat suitability. The high regression coefficients applied to the pixels classified as ponderosa pine created these areas of falsely designated suitable habitat. Many of these scattered pixels classified as ponderosa pine (ponderosa pine >70% canopy closure and ponderosa pine 40-70% canopy closure) could probably of been removed from the GIS analysis. One way to remedy this would be to place a minimum size limit on all ponderosa pine areas using some type neighborhood analysis procedure.

Core areas of the region classified as ponderosa pine would have been retained and those smaller areas classified as ponderosa pine, which provide inadequate thermal, security, and hiding cover would have been removed.

Another issue to be recognized is the questionable accuracy of the elk locational data. Stating exactly what the accuracy of the telemetry data is impossible. A good estimate is +/- 100 m. Potential miscalculations may arise when analyzing a point coverage with an accuracy of +/- 100 m in conjunction with several GIS layers that have a grid cell size of 30 m. One option would be to scale up the GIS layers to be more conducive with the point coverage's accuracy. This option was determined inadequate for this study due to the highly heterogeneous landscape features found in region, which would have been lost in the scaling process. Another option realized upon completion of this study would be to analyze a predetermined area (focal window) around each elk point for each GIS layer and generate a majority value for that point rather than taking the value of the 30 m grid cell on which the point falls.

An additional concern to be noted is the temporal differences in the landcover data and the elk location data. The landcover map was created from satellite imagery obtained during the 1997 growing season. The elk location data was collected over a 2 1/4-year time span. Annual cropping rotations from year to year could have changed landcover type habitat use statistics. What might have been winter wheat one year could have been fallow or alfalfa the next year. This may or may not influence the overall spatial distribution of the elk herds areas, but may in fact affect distribution within these herd areas. Instead of pooling the data as I did, one may want to analyze the habitat use data on a yearly basis and also retain the seasonal component of elk habitat use.

Suggested Future Research

The elk in the Pine Ridge region inhabit two spatially disjunct areas with no emigration or immigration occurring between the two herds. Suitable habitat exists between both herds based on the results of this project. The question is why don't elk inhabit other areas in the region that also seem to offer suitable elk habitat? Stillings (1999) believes that the annual harvest of elk in the region is suppressing the population to a point well below the carrying capacity of the area. These low densities are apparently not stimulating elk movement (emigration) into areas previously uninhabited. Hypothetically, if the population were allowed to increase, dispersal of elk into these previously uninhabited areas would occur.

Suggested future research might include plotting individual female elk locations and travel paths to better understand elk habitat use and movement. By analyzing elk movements seasonally and annually, migration patterns might be determined (if any exits) and what types of biophysical and/or anthropogenic habitat variables could be limiting elk dispersal movements to other parts of the region found. Other research efforts could be measuring landscape structure and spatial heterogeneity for areas presently inhabited by elk. Patch size, fractal dimension, core area, contagion and interspersion are just a few landscape-level metrics that are measurable and thought to influence organism habitat selection. By measuring these metrics for elk-use areas, one may identify phenomena that distinguish use from non-use areas not previously recognized and examined in this study.

BIBLIOGRAPHY

Adams, A. W. and D. K. Edwards, 1987. *Willamette elk habitat mapping and inventory*, Project number W-78-R-6, Wildlife Research Report Number 17, Oregon Department of Fish and Wildlife, Portland, Oregon.

Agee, K. J., S. C. F. Stitt, M. Nyquist, and R. Root, 1989. A geographic analysis of historical grizzly bear sightings in the North Cascades, *Photogrammetric Engineering and Remote Sensing,* 55(11):1637-1642.

Anderson, S. H. and K. J. Gutzwiller, 1994. Habitat evaluation methods. In T. A. Bookhout editor. *Research and management techniques for wildlife and habitats*, Fifth ed., The Wildlife Society, Bethesda, Maryland, pp. 592-606.

Bian, L. and E. West, 1997. GIS modeling of elk calving habitat in a prairie environment with statistics, *Photogrammetric Engineering and Remote Sensing,* 63(2):161-167.

Bright, L. R., 1981. *Elk habitat inventory and mapping utilizing Landsat satellite data,* Wildlife Research Report Number 11, Oregon Department of Fish and Wildlife, Portland, Oregon.

Brunt, K., 1990. Application of a Geographic Information System (GIS) to test models of Vancouver Island Roosevelt elk habitat suitability, *1990 Proceedings of the Western States and Provinces Elk Workshop,* California Fish and Game, pp. 1-7.

Cole, E. K., M. D. Pope, and R. G. Anthony, 1997. Effects of road management on movement and survival of Roosevelt elk, *Journal of Wildlife Management*, 61(4):1115-1126.

Cook, J. G., L. L. Irwin, L. D. Bryant, R. A. Riggs, and J. W. Thomas, 1998. Relations of forest cover and condition of elk: a test of the thermal cover hypothesis in summer and winter, *Wildlife Monographs*, 141:1-61.

Cooperrider, A, Y., 1996. Habitat evaluation methods. In A. Y. Cooperrider, R. J. Boyd, and H. R. Stuart editors. *Inventory and Monitoring of Wildlife Habitat,* U. S. Department of the Interior, Bureau of Land Management, pp.757-776.

Cover, M., 2000. *Ecology of elk in the Pine Ridge of Northwestern Nebraska: Seasonal distribution, characteristics of wintering sites, and herd health*, M. S. Thesis, University of Nebraska, Lincoln.

Forbes, K. M. and J. W. Merchant, 1998. *Bighorn sheep habitat assessment of the Pine Ridge of Nebraska*, Technical Report, Center for Advanced Land Management Information Technologies, University of Nebraska, Lincoln.

Herr, A. M. and L. P. Queen, 1993. Crane habitat evaluation using GIS and remote sensing, *Photogrammetric Engineering and Remote Sensing*, 59(10):1531-1538.

Hodgson, M. E., J. R. Jensen, H. E. Mackey, Jr., and M. C. Coulter, 1988. Monitoring wood stork foraging habitat using remote sensing and geographic information systems, *Photogrammetric Engineering and Remote Sensing*, 54(11):1601-1607.

Homer, C. G., T. C. Edwards, R. D. Ramsey, and K. P. Price, 1993. Use of remote sensing methods in modeling sage grouse winter habitat, *Journal of Wildlife Management*, 57(1):78-84.

Huber, T. P., 1992-93. Integrated remote sensing and GIS techniques for elk habitat management, *Journal of Environmental Systems*, 22(4):325-339.

Huber, T. P. and K. E. Casler, 1990. Initial analysis of Landsat TM data for elk habitat mapping, *International Journal of Remote Sensing*, 11(5):907-912.

Jensen, J., 1996. *Introductory Digital Image Processing: A Remote Sensing Perspective* (second edition), New Jersey: Prentice Hall.

Johnson, B. K., J. W. Kern, M. J. Wisdom, S. L. Findholt, and J. G. Kie, 2000. Resource selection and spatial separation of mule deer and elk during spring, *Journal of Wildlife Management*, 64(3):685-697.

Jones, J. K. Jr., D. M. Armstrong, R. S. Hoffman, and C. Jones, 1983. *Mammals of the Northern Great Plains*, University of Nebraska Press, Lincoln, Nebraska.

Kaul, R. B. and S. B. Rolfsmeier, 1993. *Native vegetation of Nebraska*, Conservation and Survey Division, Institute of Agriculture and Natural Resources, University of Nebraska, Lincoln.

Leckenby, D. A., 1984. *Elk use and availability of cover and forage habitat components in the Blue Mountains, Northeast Oregon, 1976-1982*, Wildlife Research Report Number 14, Oregon Department of Fish and Wildlife, Portland, Oregon.

Leckenby, D. A., D. L. Isaacson, and S. R. Thomas, 1985. Landsat application to elk habitat management in northeast Oregon, *Wildlife Society Bulletin*, 13(2):130-135.

Lyon, J. G., 1983. Landsat-derived land-cover classifications for locating potential kestrel nesting habitat, *Photogrammetric Engineering and Remote Sensing*, 49(2):245-250.

Lyon, L. J., 1979. Habitat effectiveness for elk as influenced by roads and cover, *Journal of Forestry*, 77:658-660.

Lyon, L. J., 1983. Road density models describing habitat effectiveness for elk, *Journal of Forestry*, 81:592-594, 613.

Mladenoff, D. J., T. A. Sickley, R. G. Haight, and A. P. Wydeven, 1995. A regional analysis and prediction of favorable gray wolf habitat in the northern Great Lakes region, *Conservation Biology*, 9(2)279-294.

Mladenoff, D. J., T. A. Sickley, 1998. Assessing potential gray wolf restoration in the northeastern United States: A spatial prediction of favorable habitat and potential population levels, *Journal of Wildlife Management*, 62(1)1-10.

Nebraska Game and Parks Commission, 1995. *Nebraska elk management plan*, Nebraska Game and Parks Commission, Lincoln, Nebraska.

Ormsby, J. P. and R. S. Lunetta, 1987. Whitetail deer food availability maps from thematic mapper data, *Photogrammetric Engineering and Remote Sensing*, 53(8):1081-1085.

Pereira, J. M. C. and R. M. Itami, 1991. GIS-based habitat modeling using logistic multiple regression: a study of the Mt. Graham red squirrel, *Photogrammetric Engineering and Remote Sensing*, 57(11):1475-1486.

Rost, G. R. and J. A. Bailey, 1979. Distribution of mule deer and elk in relation to roads, *Journal of Wildlife Management*, 43(3):634-641.

Sawyer, H. H., 1997. *Evaluation of a summer elk model and sexual segregation of elk in the Bighorn Mountains, Wyoming*, M. S. Thesis, University of Wyoming, Laramie.

Skovlin, J. M., 1982. Habitat Requirements and Evaluations, In J. W. Thomas and D. E. Toweill editors. *Elk of North America: Ecology and Management*, U. S. Department of Agriculture, Forest Service, pp. 369-413.

Stenback, J. M., C. B. Travlos, R. H. Barrett, and R. G. Congalton, 1987. Application of remotely sensed digital data and a GIS in evaluating deer habitat suitability on the Tehama Deer winter range, *GIS '87 - San Francisco, Second Annual International Conference, Exhibits and Workshops on Geographic Information Systems*, pp. 440-445.

Stillings, B., 1999. *Ecology of elk in northwestern Nebraska: Demographics, effects of human disturbance, and characteristics of calving habitat*, M. S. Thesis, University of Nebraska, Lincoln.

Stoms, D. M., F. W. Davis and C. B. Cogan, 1992. Sensitivity of wildlife habitat models to uncertainties in GIS data, *Photogrammetric Engineering and Remote Sensing*, 58(6):843-850.

SAS Institute Inc., 1999. *SAS/STAT User's Guide, Version 7.1*, SAS Institute, Cary, North Carolina.

Thomas, J. W., H. Black, Jr., R. J. Scherzinger, and R. J. Pedersen, 1979. Deer and elk. In J. W. Thomas editor. *Wildlife habitats in managed forest, the Blue Mountains of Oregon and Washington*, USDA, Agricultural Handbook No. 553, pp.104-127.

_______, D. A. Leckenby, L. J. Lyon, L. L. Hicks, and C. L. Marcum, 1988a. *Habitat-effectiveness index for elk on the Blue Mountain winter ranges*, Gen. Tech. Rep. PNW-GTR-218, USDA, Forest Service, Pacific Northwest Research Station, Portland, Oregon.

_______, D. A. Leckenby, L. J. Lyon, L. L. Hicks, and C. L. Marcum, 1988b. *Integrated management of timber-elk-cattle: interior forest of western North America*, Gen. Tech. Rep. PNW-GTR-225, USDA, Forest Service, Pacific Northwest Research Station, Portland, Oregon.

U.S. Fish and Wildlife Service, 1981. *Standards for the development of habitat suitability index models*, Ecological Services Manual 103, U. S. Department of Interior, Fish and Wildlife Service, Government Printing Office, Washington, D.C.

Unsworth, J. W., L. Kuck, E. O. Garton, B. R. Butterfield, 1998. Elk habitat selection on the Clearwater National Forest, Idaho, *Journal of Wildlife Management*, 62(4):1255-1263.

Van Deelen, T. R., L. B. Mckinney, M. G. Joselyn, and J. E. Buhnerkempe, 1997. Can we restore elk to southern Illinois? The use of existing digital landcover data to evaluate potential habitat, *Wildlife Society Bulletin*, 25(4):886-894.

Wisdom, M. J., L. R. Bright, C. G. Carey, W. W. Hines, R. J. Pederson, D. A. Smithey, J. W. Thomas, and G. W. Witmer, 1986. *A model to evaluate elk habitat in western Oregon*, R6-F&WL-216, USDA, Forest Service, Pacific Northwest Research Station, Portland, Oregon.

Witmer, G. W., M. Wisdom, E. P. Harshman, R. J. Anderson, C. Carey, M. P. Kuttel, I. D. Luman, J. A. Rochelle, R. W. Scharpf, and D. Smithey, 1985. Deer and elk. In E. R. Brown editor. *Management of wildlife and fish habitats in forests of western Oregon and Washington*, R6-f&WL-192, USDA, Forest Service, U.S. Govt. Print. Off. Washington, D.C., pp. 231-258.

Table 1. Landcover classification scheme for the Pine Ridge study area, 1997.

Ponderosa Pine (>70% canopy closure)	Other Agriculture
Ponderosa Pine (40-70% canopy closure)	Fallow Agriculture
Riparian Woodland	Alfalfa/Hay
Western Mixedgrass Prairie	Barren/Sand/Rock Outcrop
Lowland Tallgrass Prairie	Wetland
Small Grains Agriculture	Open Water

Table 2. Habitat variable (aspect, slope, distance to a road, road density, and distance from the ponderosa pine edge) measurements for elk in the Bordeaux Creek area and Hat Creek area (1995-1997).

GIS Data Layer		**Bordeaux Creek locational data**	**Hat Creek locational data**
Aspect (degrees)			
	315-45	31% (n=921)	31% (n=851)
	46-135	27% (n=812)	28% (n=785)
	136-225	14% (n=423)	17% (n=479)
	226-314	28% (n=855)	24% (n=661)
		Mean	***Mean***
Slope (degrees)		8.42	11.18
Distance to a road (m)		521	549
Road density (km/km^2)		0.67	0.74
Distance from cover areas (m)		76.2	70.0
Distance into cover areas (m)		73.6	36.2

Table 3. Habitat variable (aspect, slope, distance to a road, road density, and distance from the ponderosa pine edge) measurements for all elk locations (Bordeaux Creek area and Hat Creek area) and a random point coverage.

GIS Data Layer		Elk Locations (Bordeaux and Hat Creek)		Random Locations	
Aspect (degrees)					
	315-45	31% (n=1772)		31% (n=1782)	
	46-135	28% (n=1597)		27% (n=1567)	
	136-225	16% (n=902)		20% (n=1156)	
	226-314	26% (n=1516)		22% (n=1282)	
		Mean	***Range***	***Mean***	***Range***
Slope (degrees)		9.52	0-44.20	5.18	0-41.19
Distance to a road (m)		529.33	0-2289.65	454.01	0-2473.86
Road density (km/km^2)		0.73	0-4.41	0.95	0-5.40
Distance from cover areas (m)		90.21	0-1167	474.00	0-6557
Distance into cover areas (m)		47.63	0-524	14.00	0-606

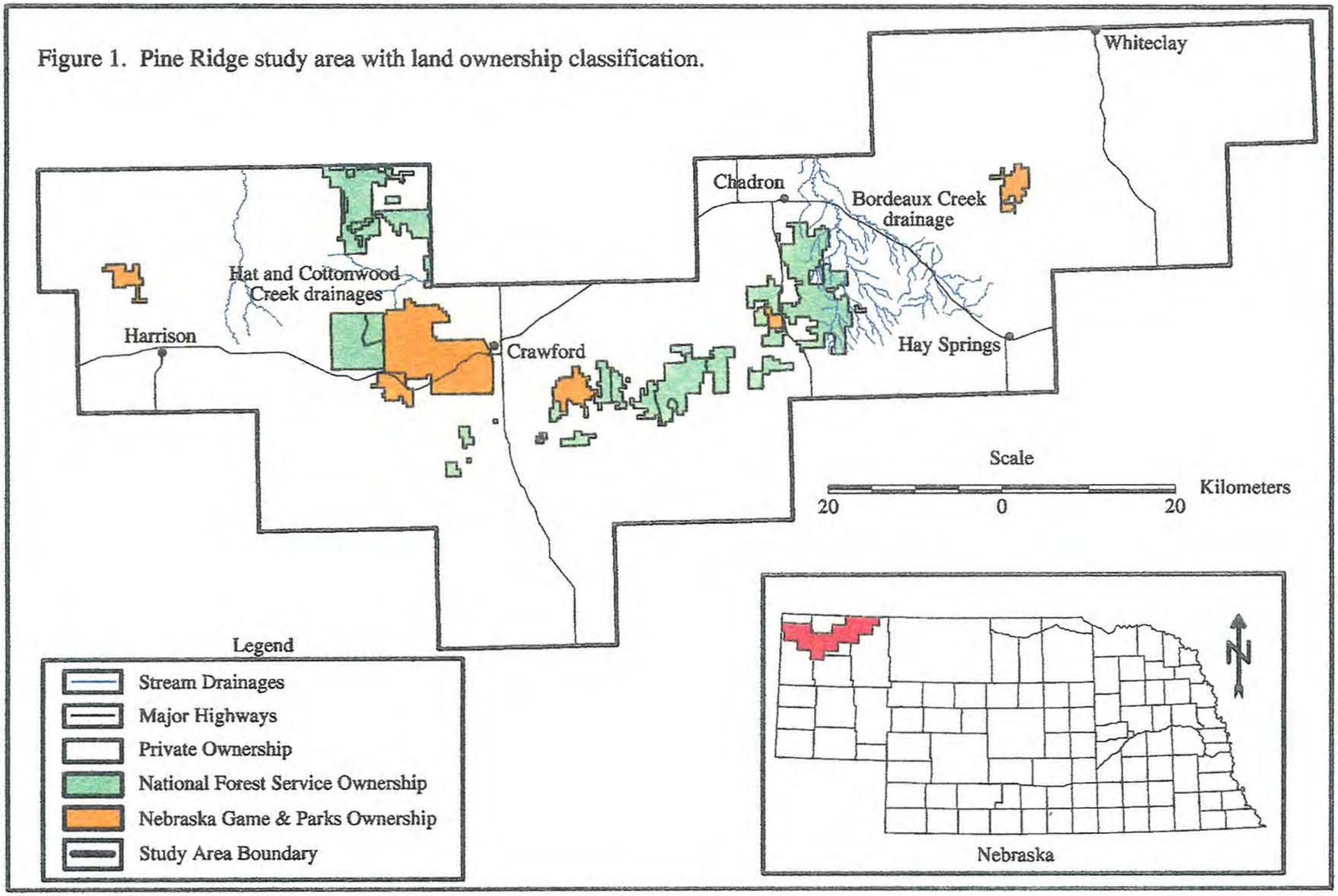
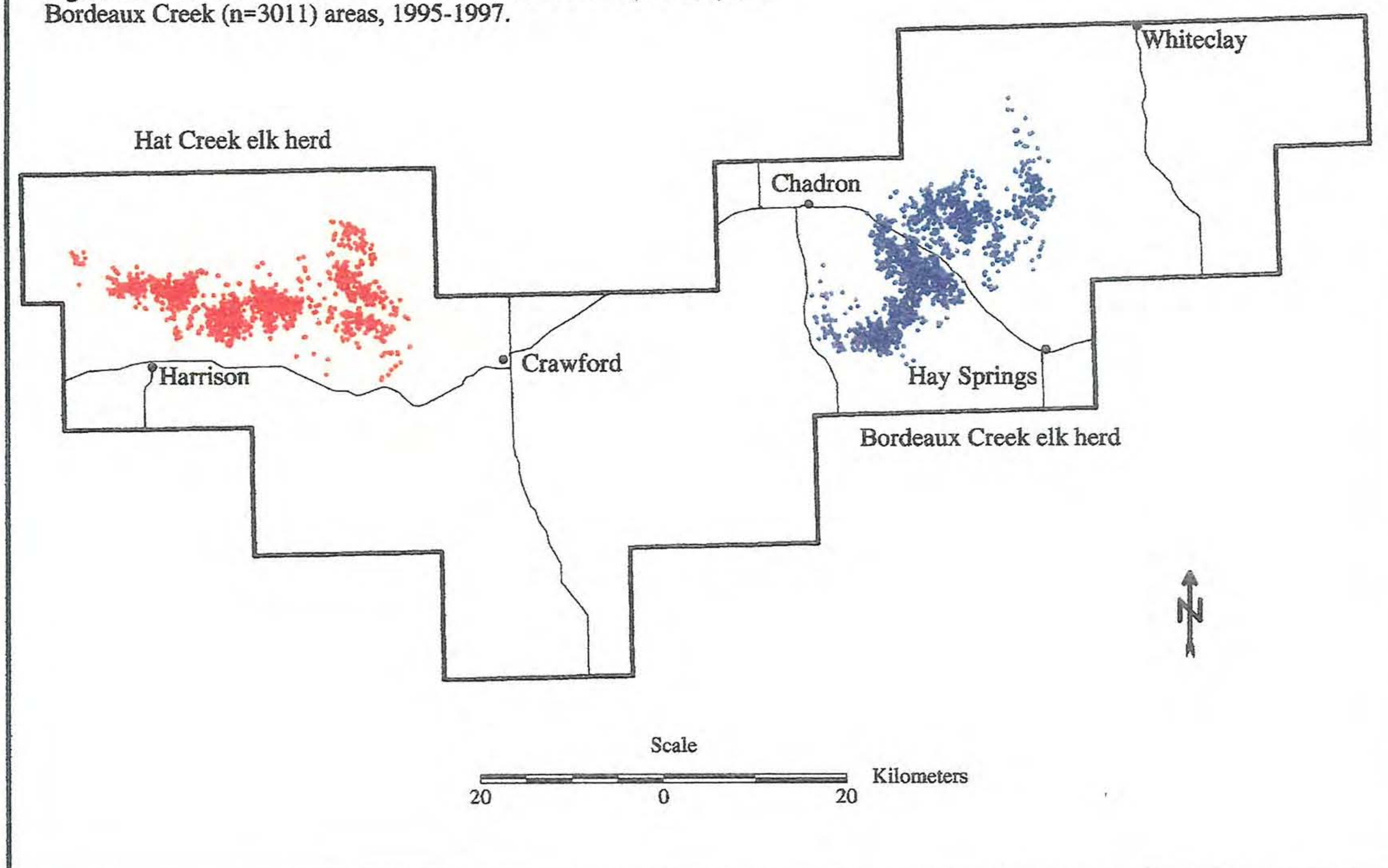


Figure 1. Pine Ridge study area with land ownership classification.

Figure 2. Distribution of elk locations in the Hat Creek (n=2776) and Bordeaux Creek (n=3011) areas, 1995-1997.



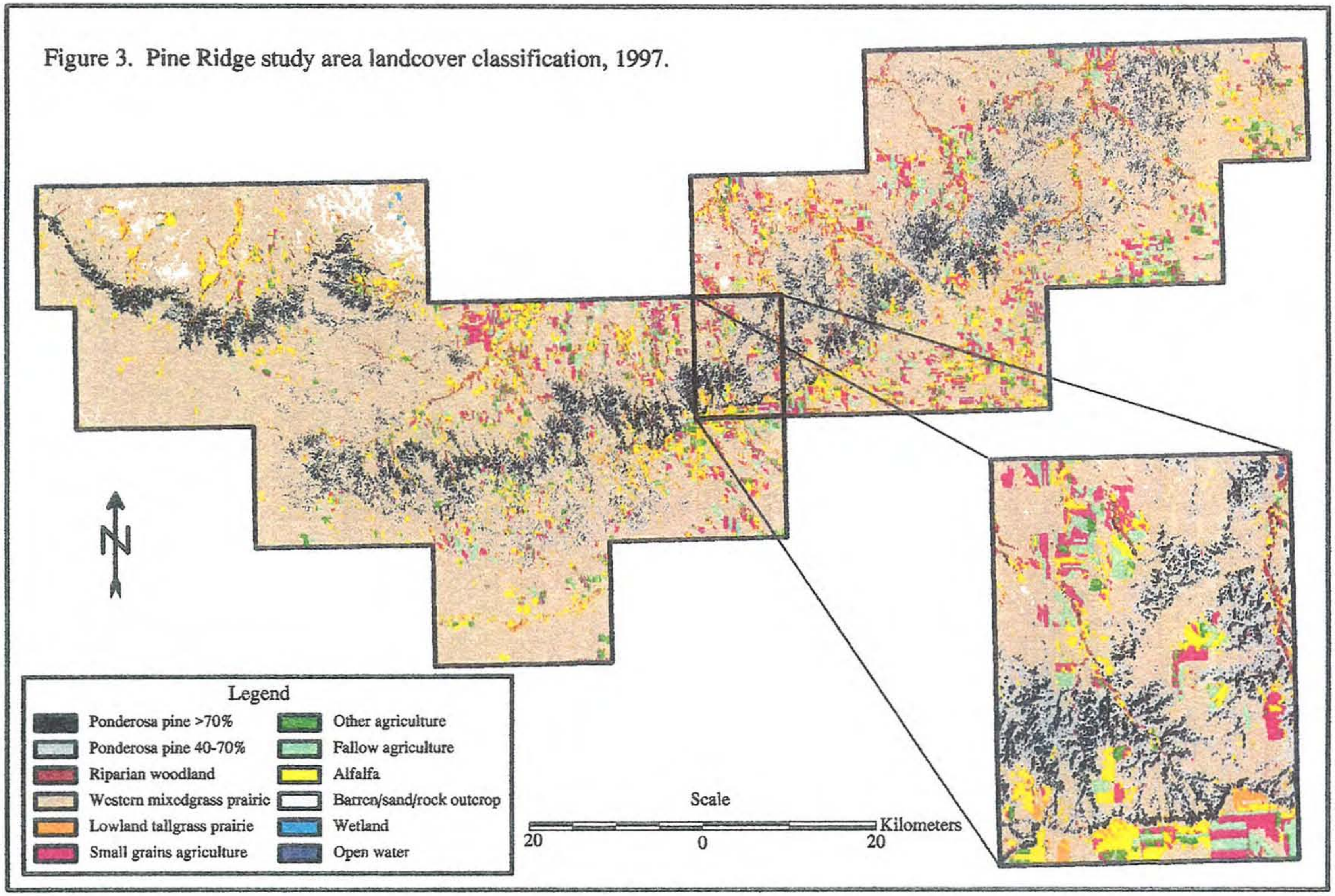


Figure 3. Pine Ridge study area landcover classification, 1997.

Figure 4. Relative distribution of landcover for the areas occupied by elk in northwestern Nebraska (entire Pine Ridge study area, Bordeaux Creek area, and Hat Creek area), 1995-1997.

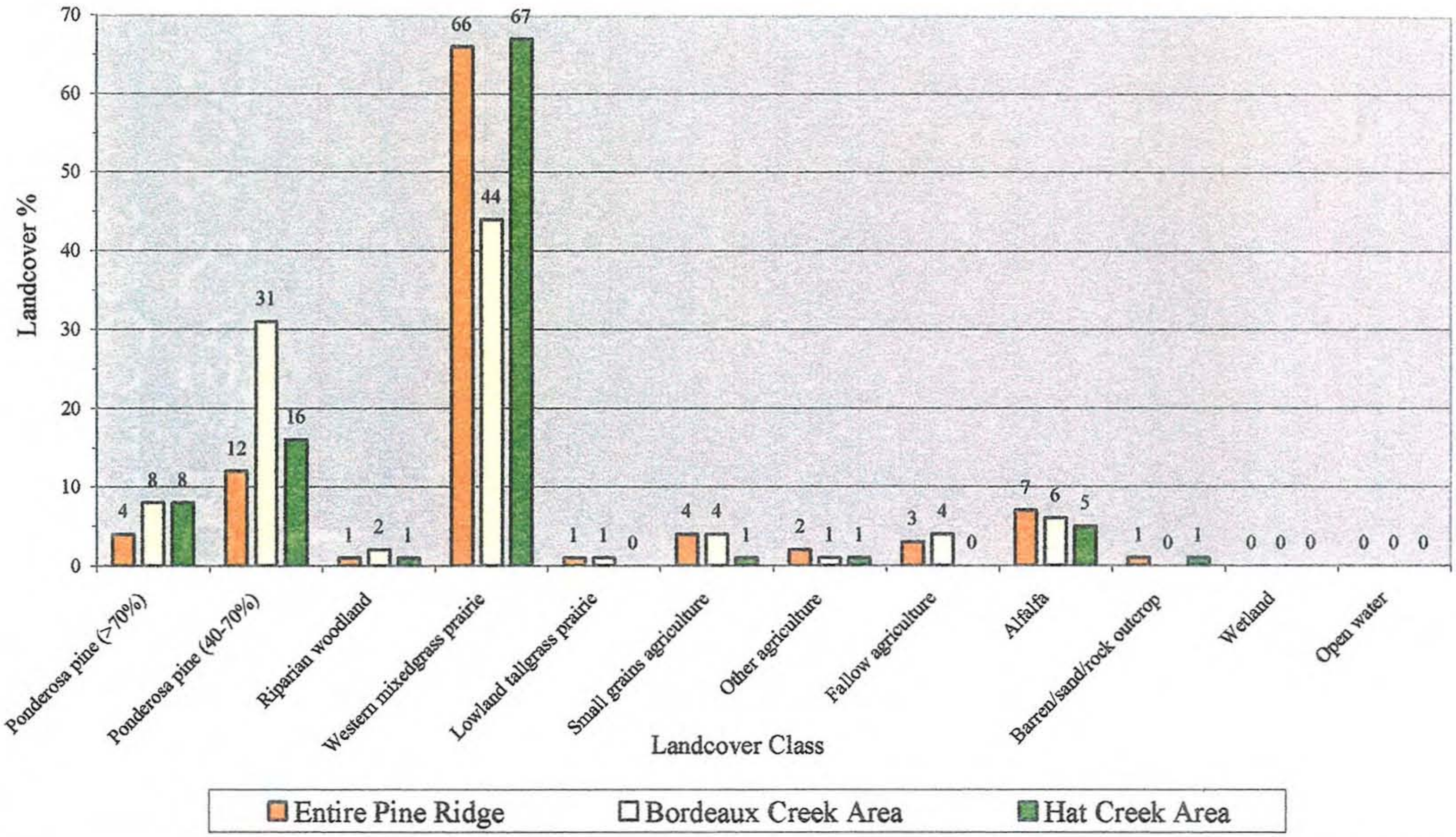


Figure 5. Hat Creek and Bordeaux Creek elk herd areas with landcover classification, 1997.

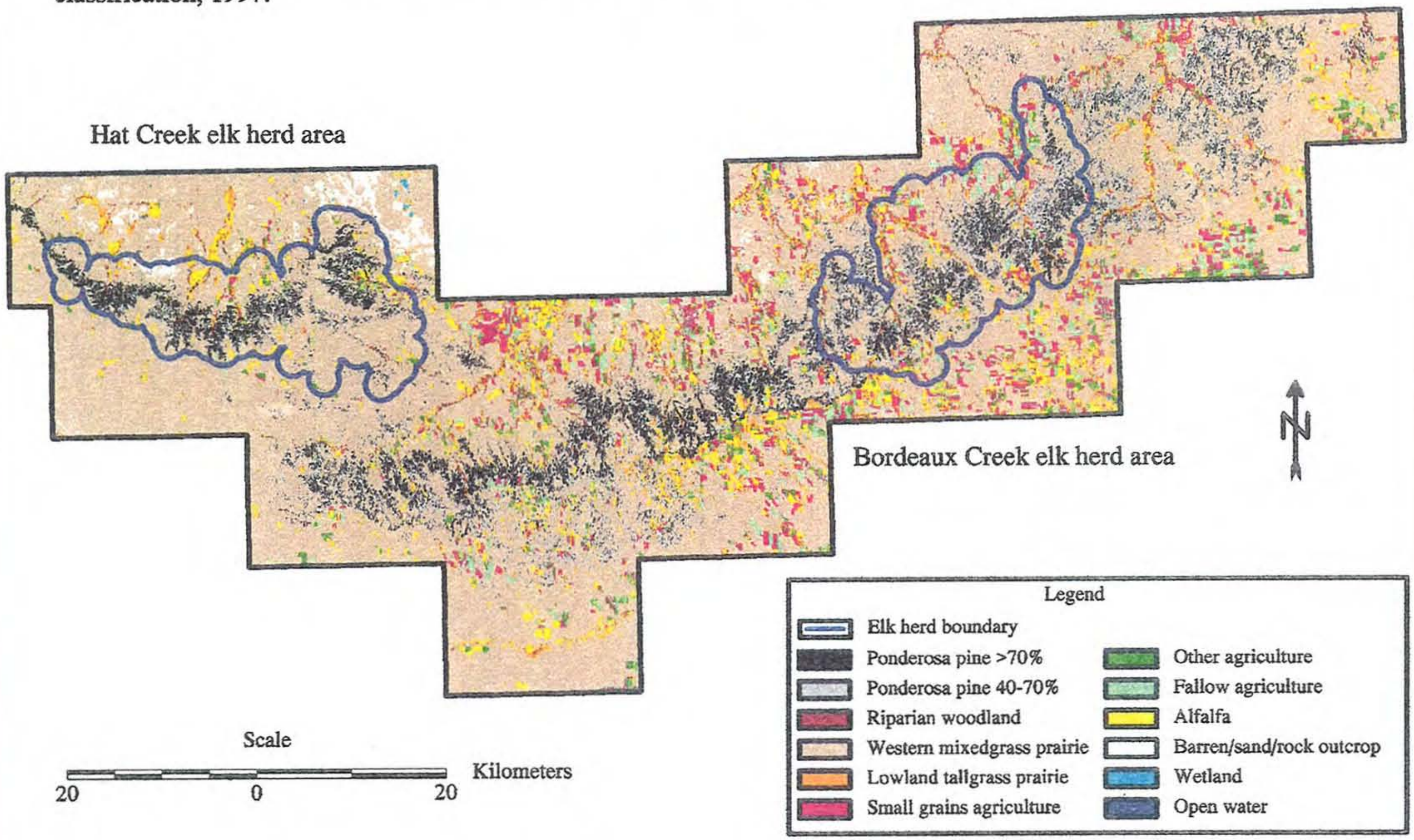


Figure 6. Relative distribution of landcovers selected by female elk in the Bordeaux Creek area and Hat Creek area, 1995-1997.

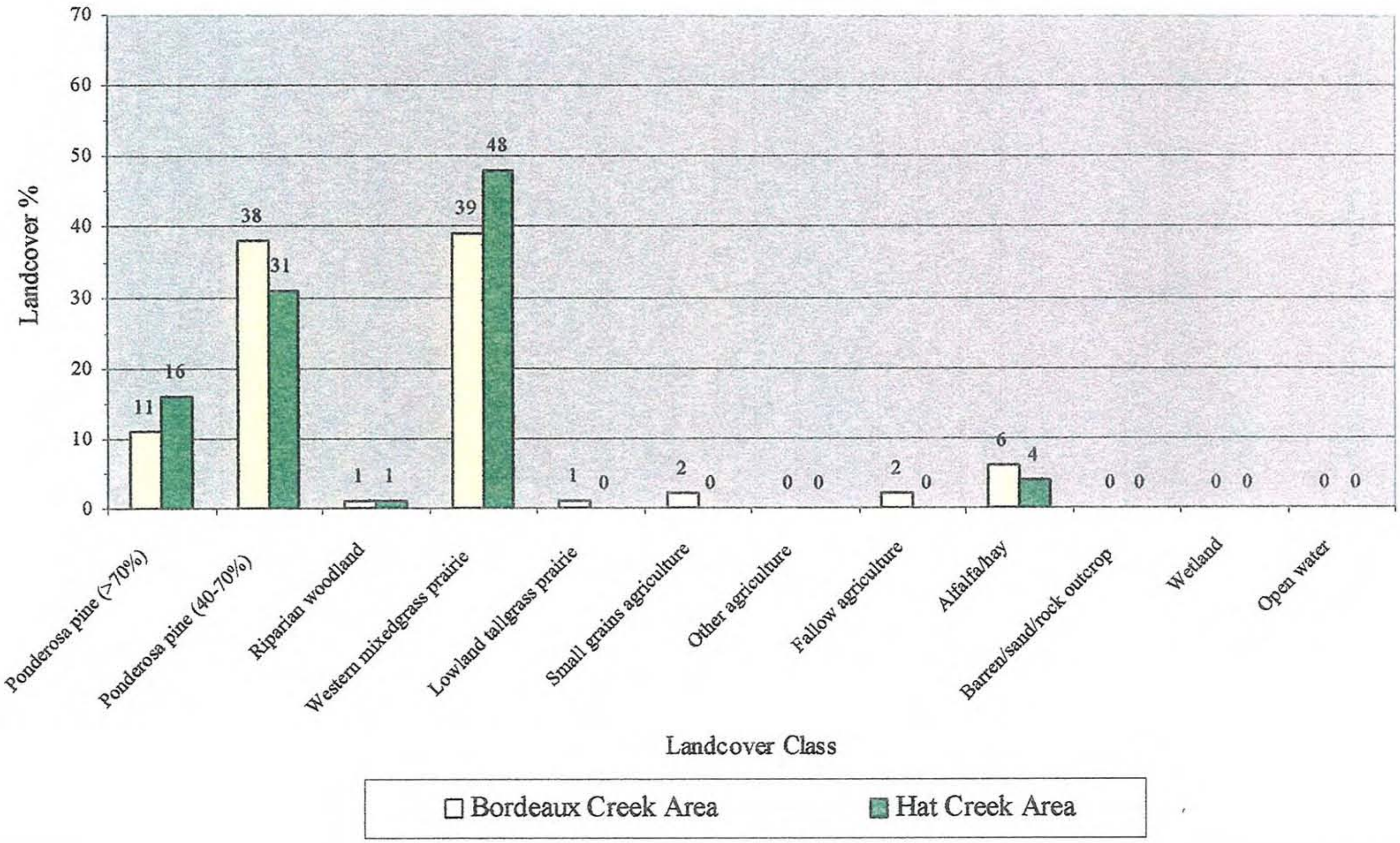


Figure 7. Relative distribution of landcovers selected by female elk in the Bordeaux Creek area during five seasons, 1995-1997.

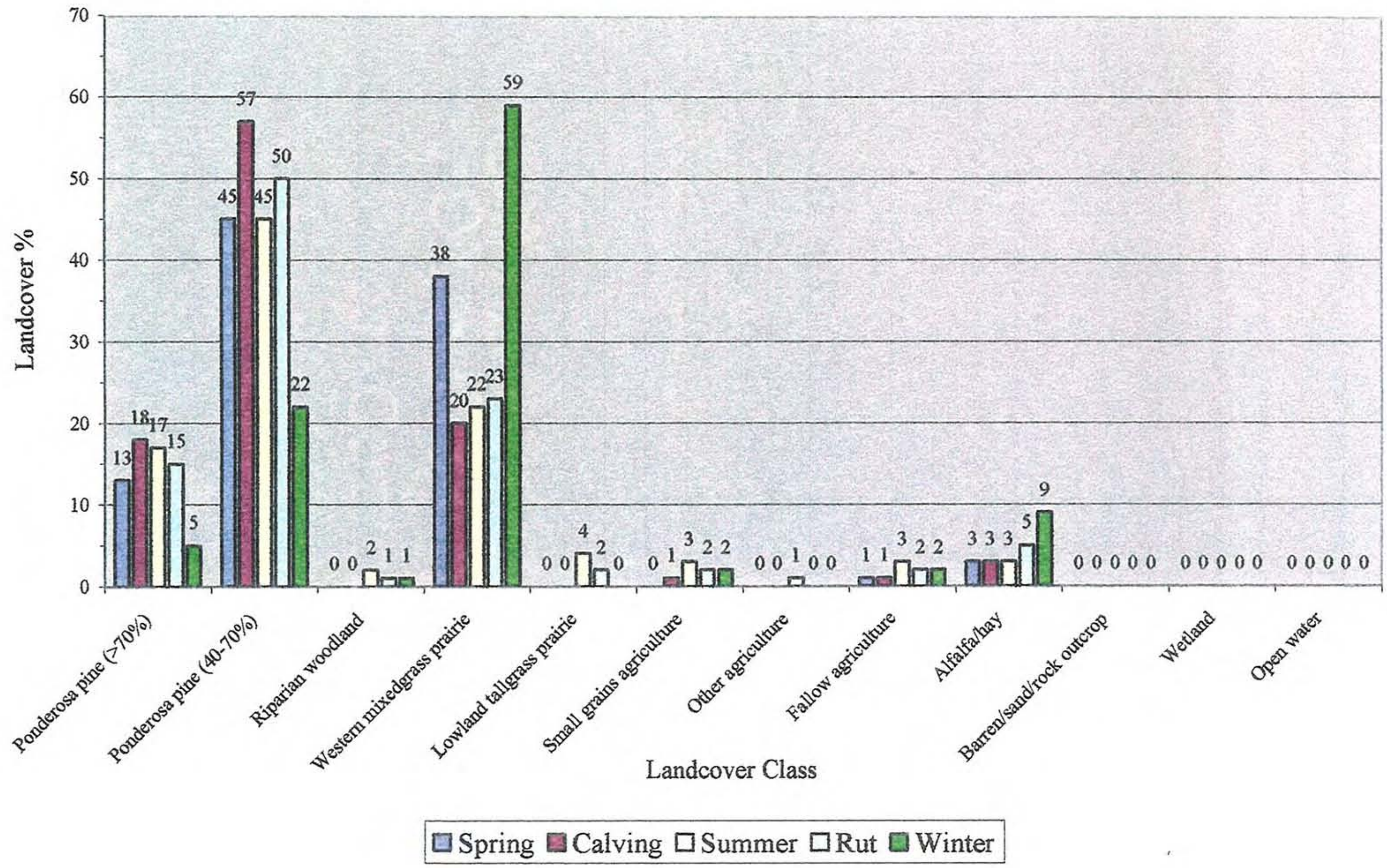


Figure 8. Relative distribution of landcovers selected by female elk in the Hat Creek area during five seasons, 1995-1997.

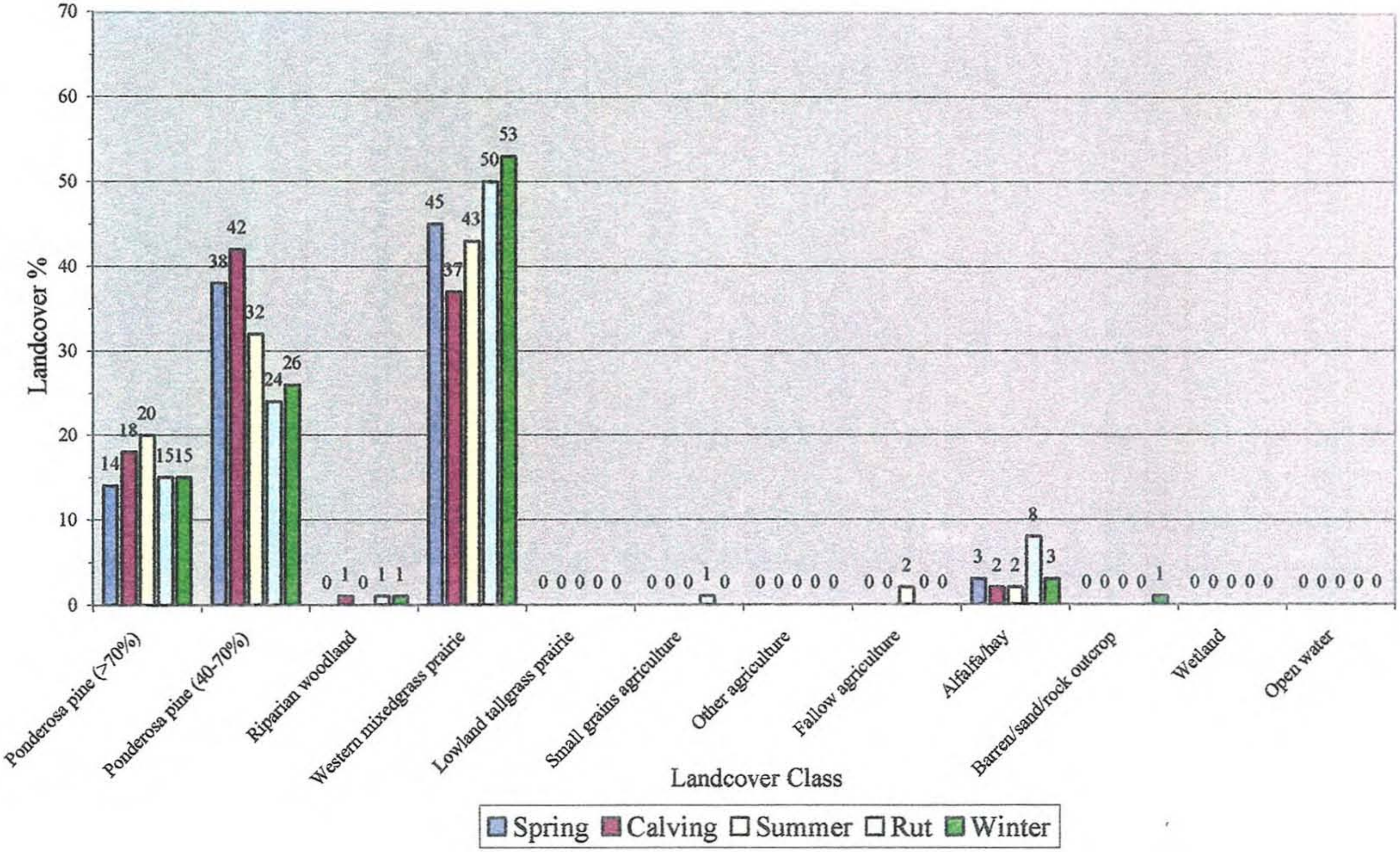


Figure 9. Pine Ridge study area distance to a road map.

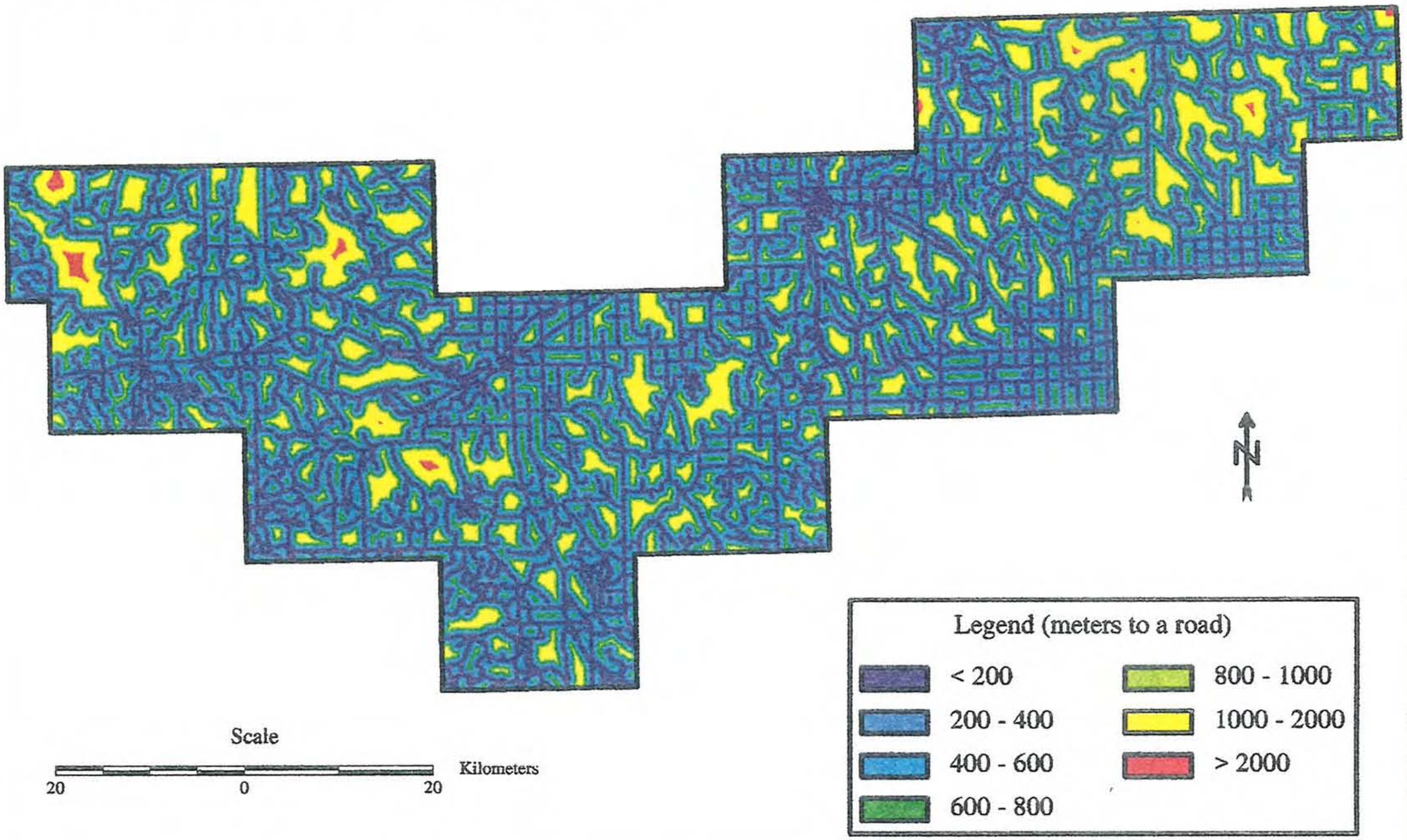


Figure 10. Categorical distribution of the "distance to a road" GIS layer for the entire study area (%).

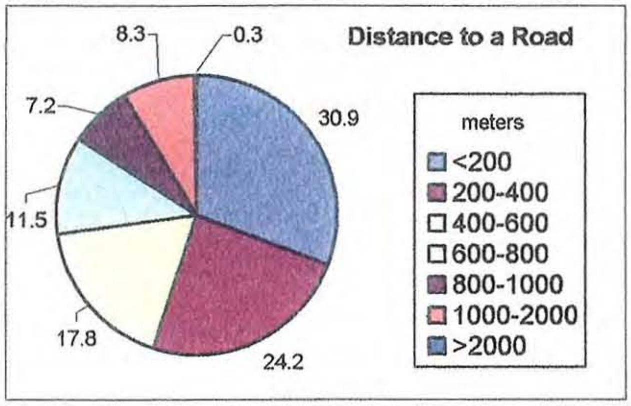


Figure 11. Pine Ridge study area road density map.

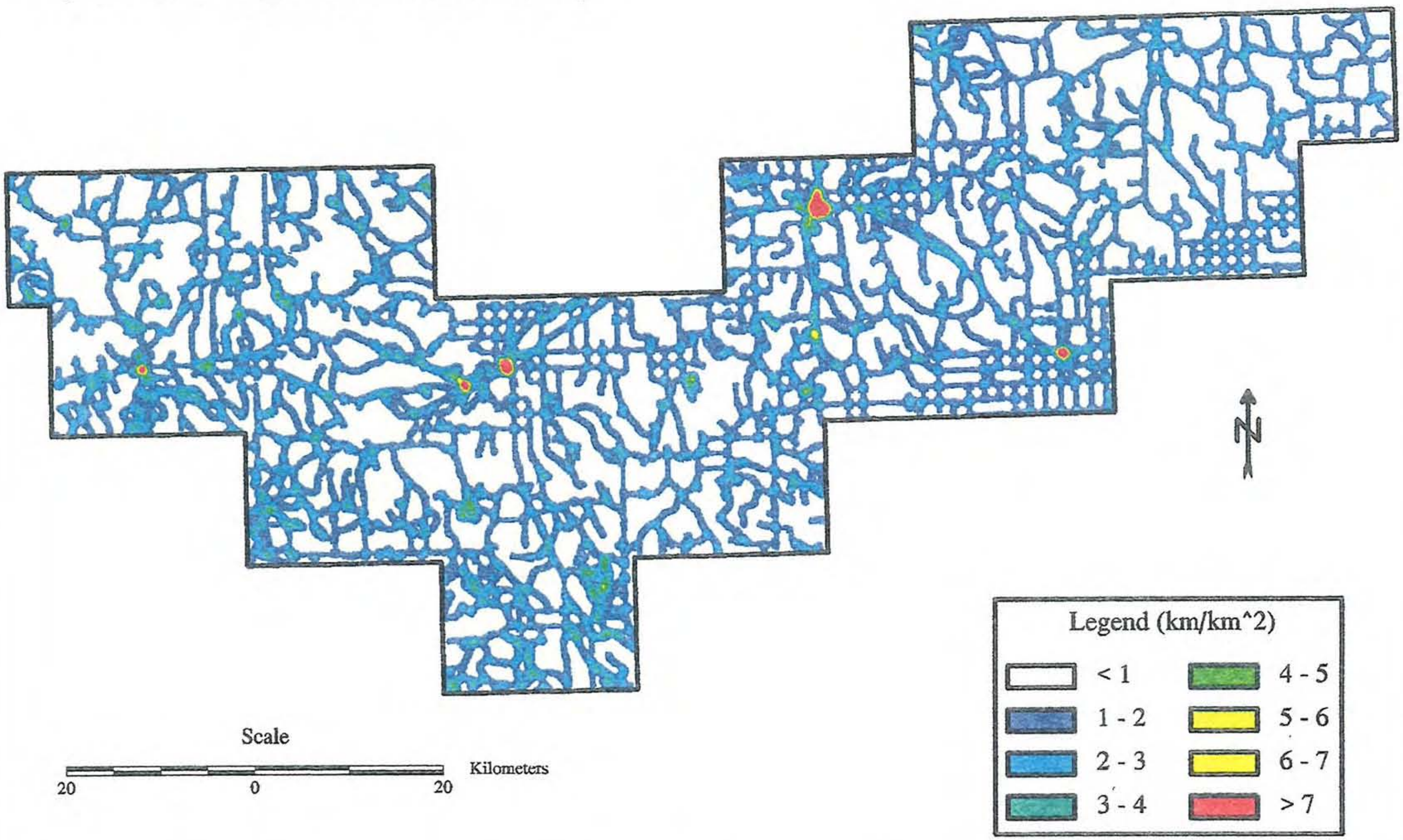


Figure 12. Categorical distribution of the "road density" GIS layer for the entire study area (%).

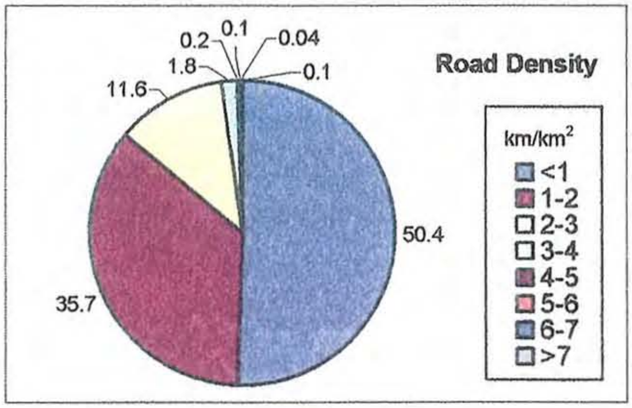


Figure 13. Pine Ridge study area aspect map.

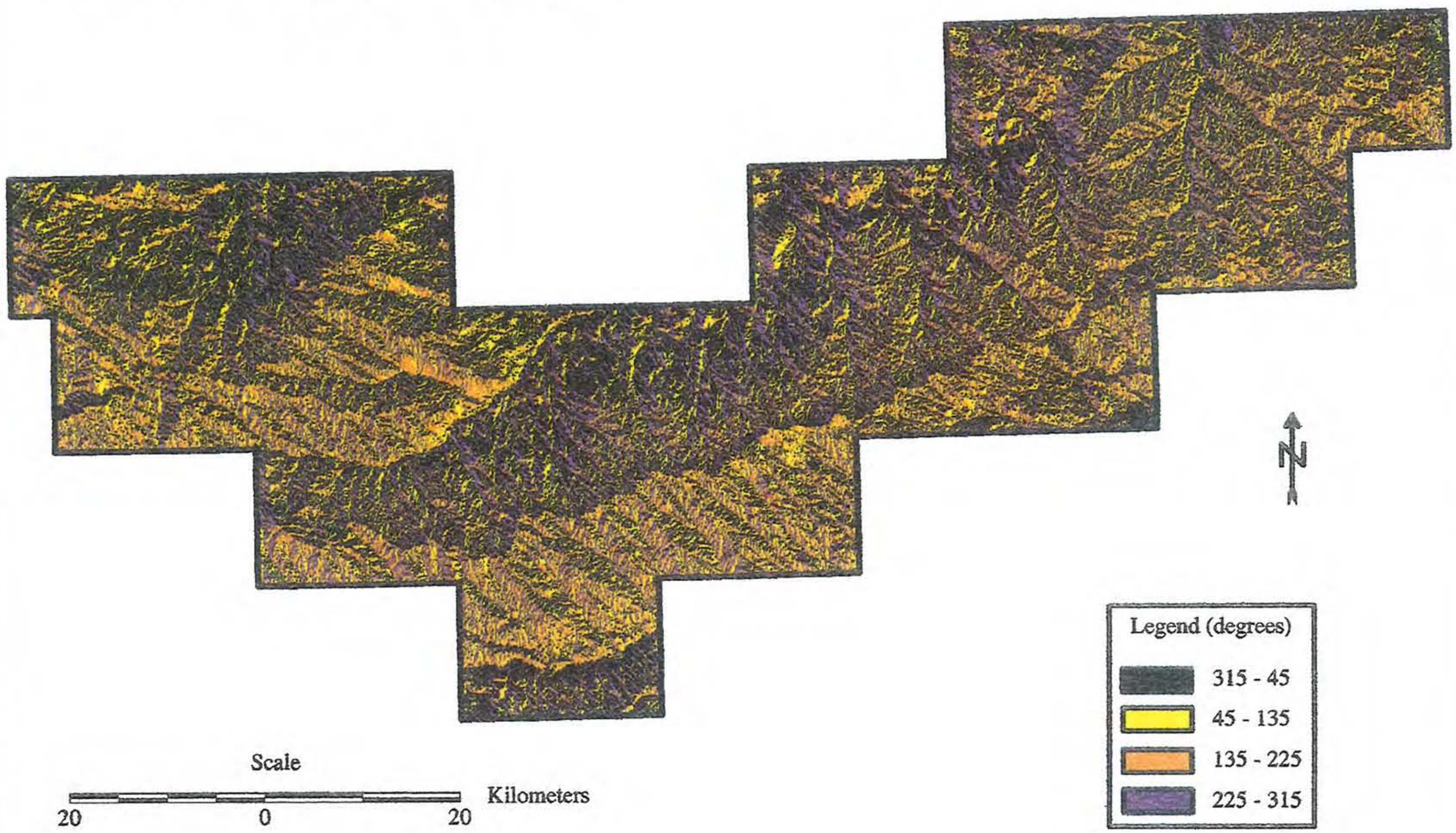


Figure 14. Categorical distribution of the "aspect" GIS layer for the entire study area (%).

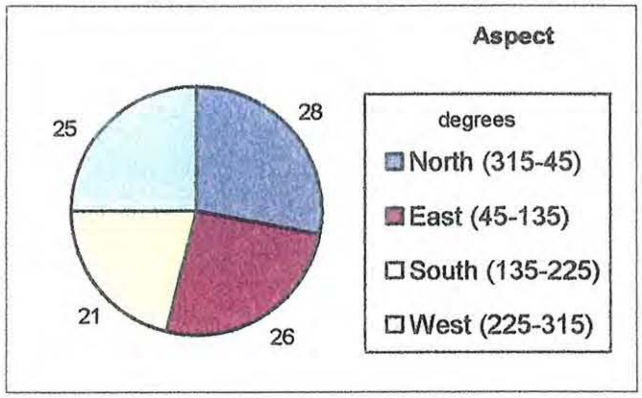


Figure 15. Pine Ridge study area slope map.

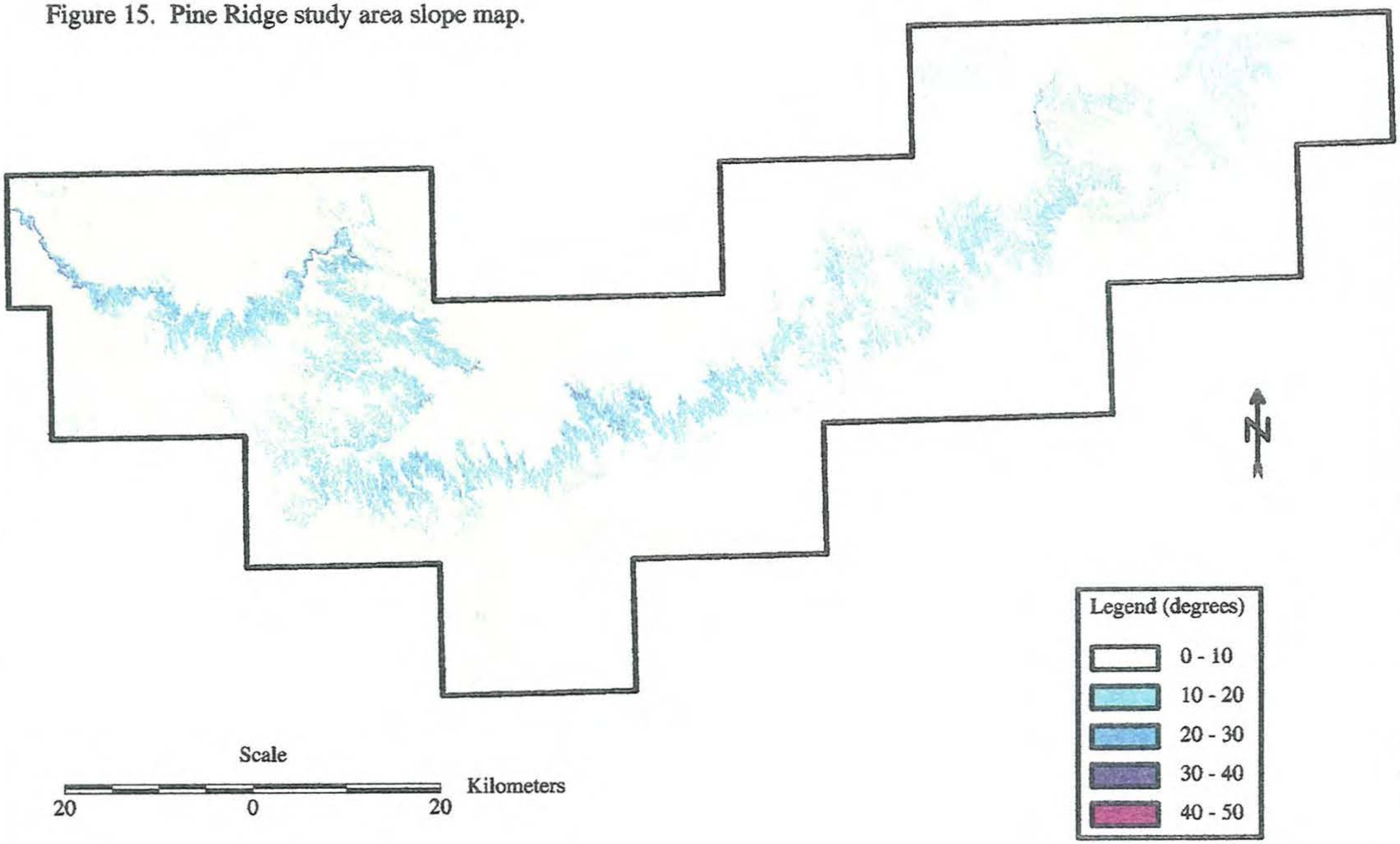


Figure 16. Categorical distribution of the "slope" GIS layer for the entire study area (%).

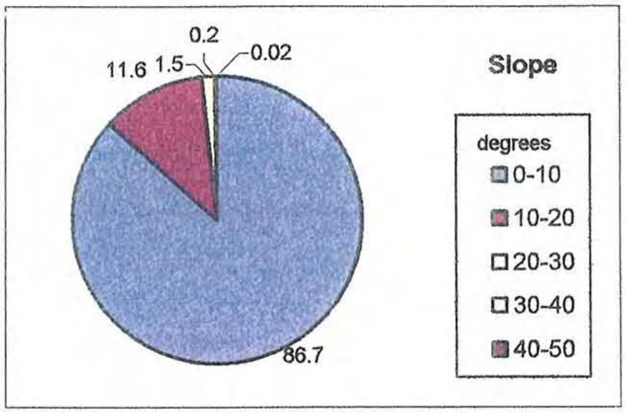


Figure 17. Pine Ridge study area distance from the ponderosa pine edge map.

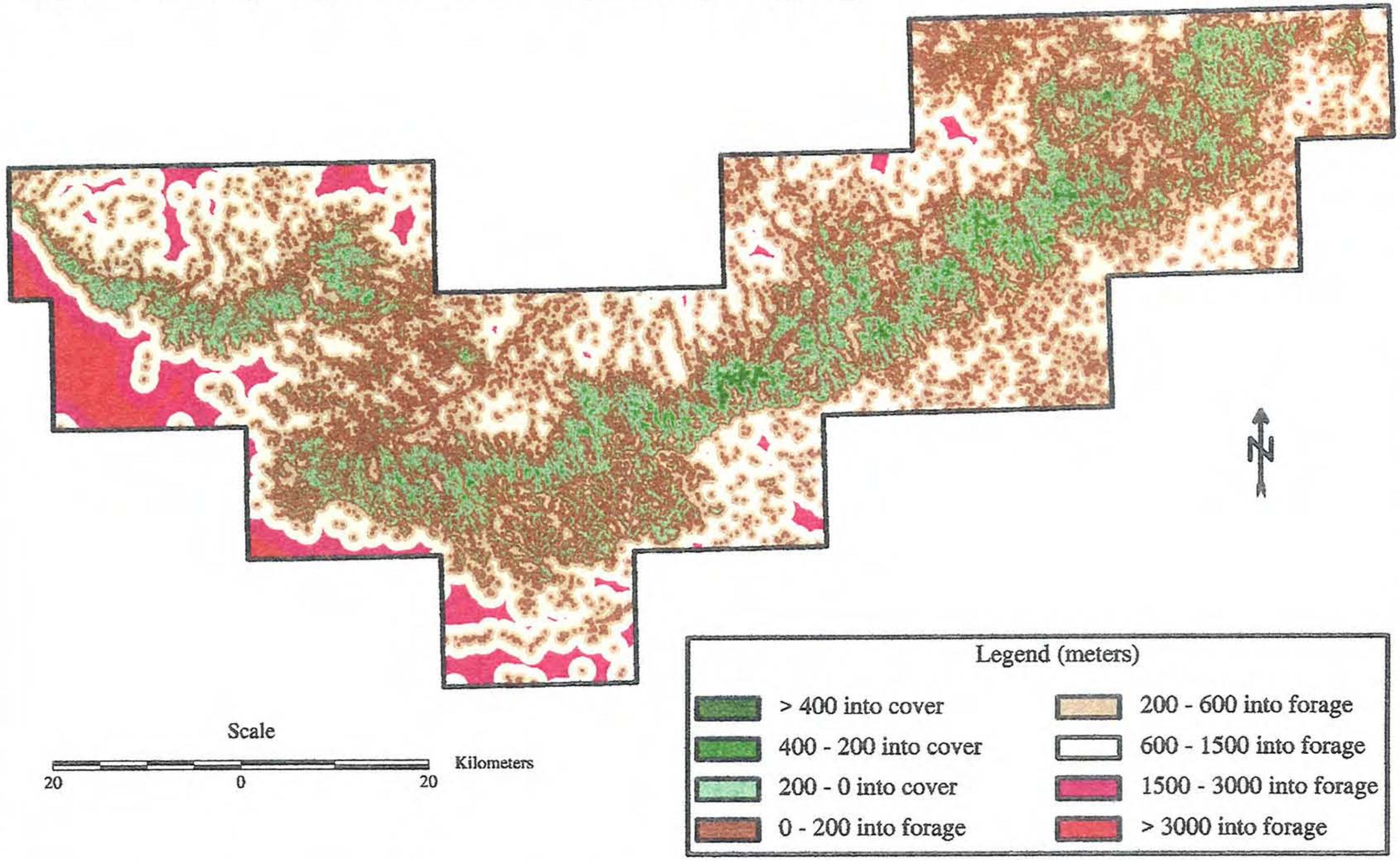


Figure 18. Categorical distribution of the "distance from the ponderosa pine edge" GIS layer for the entire study area (%).

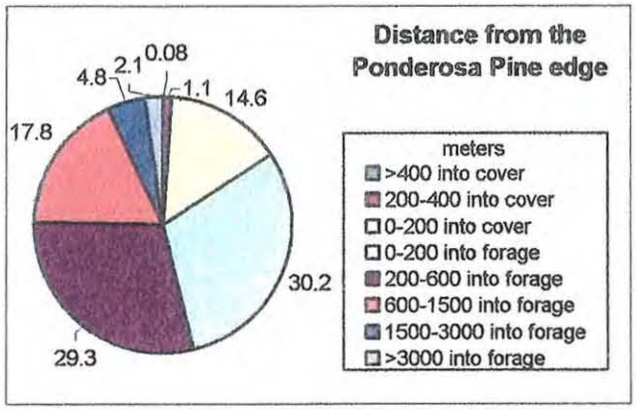


Figure 19. Spatial distribution of random points (n=5787).

Figure 20. Distribution of suitable elk habitat based on logistic regression model.